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FOOD SYSTEMS TRANSFORMATION TOWARDS SUSTAINABILITY AND HEALTHIER GLOBAL NUTRITION

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ABSTRACT

Introduction: *The global food system encompasses interconnected activities including food production, processing, distribution, consumption, and waste management. However, this system significantly contributes to environmental degradation, with approximately 30% of global greenhouse gas emissions originating from food production and its associated processes. This review addresses the urgent need to transition toward sustainable food systems that can support both human and planetary health. The objective is to explore the role of the agri-food sector, alongside governmental and other stakeholders, in promoting sustainable healthy diets—defined as dietary patterns that are health-promoting, accessible, affordable, safe, equitable, and culturally appropriate.*
Methods: *The methodological approach consisted of a comprehensive literature review, analyzing current research, reports, and policy documents to assess the effectiveness of interventions in improving nutrition and reducing environmental impact. The review also examines strategies such as food reformulation, development of functional foods, waste valorization, and public education aimed at changing consumer behavior.*
Results: *Findings highlight the critical role of sustainable food systems in addressing the double burden of malnutrition—where undernutrition and obesity coexist—and in preventing non-communicable diseases. The evidence indicates that improving food availability, affordability, and quality through coordinated actions among the agri-food sector and policymakers can significantly contribute to better health outcomes and reduced environmental impact.*
Discussion: *This review underscores the importance of systemic change in food production and consumption patterns. It concludes that equitable access to nutritious food, combined with education and innovation in food production, are essential to achieving the United Nations' Sustainable Development Goals.*

Keywords: Food system, Functional food, Food reformulation, Stakeholders, Malnutrition

1. Introduction

The transformation of global food systems has emerged as one of the most pressing challenges of the 21st century, intersecting issues of public health, environmental sustainability, and socio-economic development. According to Biesbroek et al. (2023), sustainable food systems aim to ensure equitable access to nutritious foods across all income levels while simultaneously supporting the livelihoods of smallholders and small to medium-sized enterprises, thereby fostering greater social inclusivity. This vision aligns closely with the United Nations' Sustainable Development Goals (SDGs), which highlight the central role of sustainable food systems in achieving healthy diets and broader societal well-being.
A growing body of research underlines the need for a comprehensive transformation of current food systems to address these interconnected challenges, advocating for ecologically sustainable dietary patterns that promote both nutritional health and food security. However, implementing such systemic changes remains complex and resource-intensive (Hales et al., 2024).

The food system represents a highly intricate and interdependent network encompassing agriculture, animal husbandry, food production and processing, distribution, marketing, retail, preparation, and consumption (Martinelli & Cavalli, 2019). Dietary and food choices exert substantial environmental impacts through multiple pathways, including energy consumption, land conversion, water resource depletion, and contributions to climate change (Macdiarmid, 2013). The entire food supply chain — from fertilizer production to global commodity distribution — contributes significantly to greenhouse gas emissions (Campbell et al., 2017). Food production alone accounts for approximately 30% of global greenhouse gas emissions (Bailey & Harper, 2015), illustrating its disproportionate environmental footprint. Current dietary patterns are widely regarded as unsustainable, as they rely heavily on resource-intensive foods that require large energy inputs and extensive land use, resulting in substantial ecological degradation (Martinelli & Cavalli, 2019).

Sustainable healthy diets, as defined by the World Health Organization (2019), are dietary patterns that promote comprehensive health and well-being, are accessible, affordable, safe, fair, and culturally acceptable. In response to the growing environmental and public health challenges associated with current dietary patterns, an increasing number of countries have integrated sustainability principles into their national dietary guidelines. These recommendations emphasize a shift towards predominantly plant-based diets, prioritizing seasonal and locally sourced foods, reducing food waste, and limiting the consumption of red and processed meats, ultra-processed products, and sugar-sweetened beverages (Goulding et al., 2020).Non-communicable diseases (NCDs) represent one of the most significant public health burdens worldwide, accounting for approximately 74% of all deaths in 2019 (WHO, 2021). The 2021 Global Nutrition Report underscores the urgency of addressing diet-related health risks, as more than 2.2 billion adults are now overweight or obese, with prevalence rates rising rapidly in low- and middle-income countries, particularly in urban settings(https://www.who.int/health-topics/obesity#tab=tab_1). Evidence from the Food Consumption Survey in Adults in Macedonia (2015) reflects this trend, with 62.7% of men and 48.4% of women classified as overweight or obese—figures comparable to those in many European countries (Spiroski, 2016).

Unhealthy dietary patterns remain a major modifiable risk factor for overweight, obesity, and diet-related NCDs, contributing substantially to global morbidity and mortality (Barclay & Haschke, 2015; Afshin et al., 2014).The COVID-19 pandemic further exposed the vulnerability of food systems, highlighting the critical role of adequate nutrition in population health. Malnutrition was associated with increased risk and severity of SARS-CoV-2

infection, reinforcing the importance of resilient and equitable food environments (Huizar et al., 2021; Wells et al., 2021; Pan et al., 2021).

Food choices are strongly shaped by the availability and accessibility of products within commercial food systems, upon which most populations depend for daily nourishment(White et al., 2020). In this context, agri-food by-products have attracted growing attention as a promising resource for sustainable food innovation. Due to their richness in proteins, lipids, carbohydrates, micronutrients, dietary fiber, and diverse bioactive compounds, these by-products offer significant potential for the development of novel food formulations, alternative livestock feeds, and the recovery of functional ingredients (Rațu et al., 2023).Transitioning to sustainable food systems is therefore essential to protect both human and planetary health. Achieving this transformation requires integrated, multisectoral strategies that balance ecological integrity with nutritional security and equitable access to resources, while building resilience to future global health and environmental crises.

This paper examines the current state of global food systems, identifies their environmental and nutritional impacts, and outlines key strategies for their transformation towards more sustainable and health-promoting models.

The agri-food sector as a central component of food systems transformation

The agri-food sector functions as an interconnected system comprising agriculture, food processing, and trade, which constitute the core components of this integrated network (Karwacka et al., 2020).The unsustainability of current food systems is driven by a complex interplay between environmental degradation, inefficient resource use, and nutrition-related health challenges. Modern agricultural systems are characterized by intensive production models, monocultures, and heavy reliance on synthetic fertilizers and pesticides, which contribute to soil degradation, biodiversity loss, water pollution, and increased greenhouse gas emissions (FAO, 2023). Furthermore, current food supply chains are heavily dependent on fossil fuels, long-distance transportation, and energy-intensive processing, which substantially increase the sector's carbon footprint. Approximately one-third of all food produced globally is lost or wasted each year (FAO, 2021), highlighting the systemic inefficiencies embedded across production, distribution, and consumption stages.

Commercial food systems have undoubtedly contributed to the current global state of food environments (Cetthakrikul et al., 2019). Profits can be made from a healthier and more sustainable food system, in ways that are consistent with prevention of diet-related diseases including diabetes, heart disease, stroke, and cancer. The food industry is an inevitable actor in the action to develop, distribute, and market healthier foods for society. The food industry is responding to this challenge by improving the nutritional value of food products through decreasing the levels of public health-sensitive nutrients and increasing the content of essential nutrients (fiber, micronutrients, etc.) (Barclay & Haschke, 2015). Saturated fats, industrially produced trans fats, sodium, and added sugars, which are known as dietary factors that can contribute to the risk of certain non-communicable diseases (NCDs) when consumed in excess, are now recognized and implemented in programs with criteria built on the concepts of "nutrients to limit" in multinational companies (Yach et al., 2010; PepsiCo Nutrition Criteria).

Given the significant health and economic burden of diet-related diseases, overweight status, and obesity and the need for multi-stakeholder solutions because of the multifactorial nature of the public health concerns, a coordinated national food and nutrition policy strategy should be a priority for all governments (Mozaffarian et al., 2018)a. Governments can use a spectrum of policies, from voluntary to mandatory, focused on altering consumer preferences or choice, food formulations, or food availability and accessibility.

Governments need to increase their efforts to catalyze and regulate rapid change in the food sector, through fiscal and regulatory policies that will support the implementation of nutritional strategies. In the implementation of healthy food policies, food companies should have the role of facilitators in that process and by using their expertise, innovation, and marketing to develop, distribute, and market healthier foods and create transparent, genuine partnerships with academics, advocacy groups, and the government (Mozaffarian et al., 2018a; Chen & Yang, 2021; Wang et al., 2016). In Figure 1, the food industry's role and interactions between the food industry and other stakeholders for a healthier food system are shown.

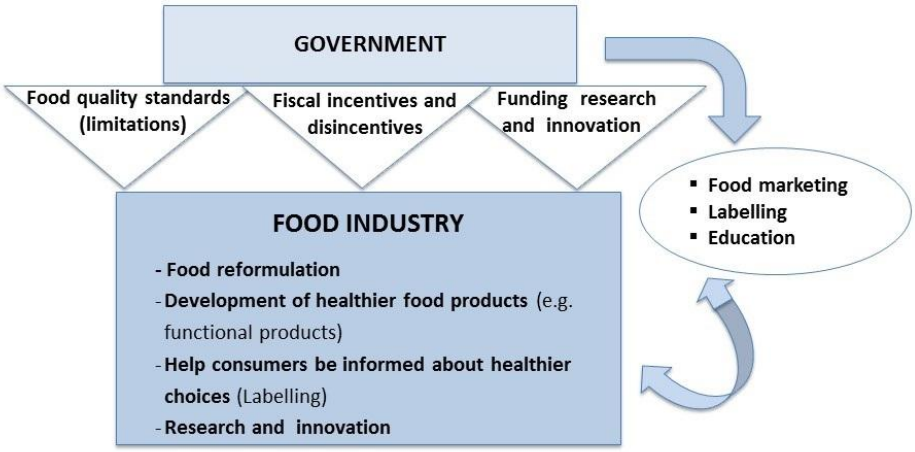

Figure 1: Food industry role and interactions between food industry and other stakeholders for a healthier food system

A law that imposes sales tax on sugar-sweetened beverages (SSB), discourages consumers from buying these beverages, and encourages manufacturers to develop low-sugar alternatives is just one example (Kobes et al., 2022). Numerous public–private partnerships nowadays (for example, the International Diabetes Federation and Nestlé) (Moodie et al., 2013) also contribute. However, some food companies have actively opposed healthier food policies, especially in low- and middle-income countries (Mozaffarian et al., 2018)a. Taking responsibility to improve the nutritional quality of food products could increase companies' chances of market success because of increased government and consumer trust and loyalty toward these companies (Harastani et al., 2020).

3. Addressing the rise of ultra-processed foods: reformulation and innovation pathways

The agri-food sector, as a central component of the global food system, holds significant responsibility for shaping the nutritional quality and sustainability of available food products. While ongoing efforts from governments and the food industry to promote healthier food environments and policies are crucial, addressing the complexity of dietary patterns requires a deeper understanding of the types of foods consumed, particularly the rising dominance of ultra-processed foods (UPFs).

Ultra-processed foods (UPFs) are defined as "formulations of ingredients, mostly of exclusive industrial use, typically created by a series of industrial techniques and processes" (FAO, 2019). There is strong nutritional epidemiological evidence of an association between UPF consumption and an increased risk of morbidity and mortality (Campbell et al., 2021). UPF products now dominate the food supplies of various high-income countries (Monteiro et

al., 2017) and it is argued that the world's population will consume more ultra-processed foods and drinks over the coming decades than ever before (Moodie et al., 2013). For example, UPFs accounted for 56.1% of the total energy ingested by the participants in the study of Juul et al., 2018, conducted among US adults. UPFs are highly profitable and mainly produced by multinational corporations (Lauber et al., 2020). UPF products are nutritionally inferior to unprocessed, minimally processed, or processed foods as they contain significantly higher proportions of carbohydrates, free sugars, total and saturated fats, salt, and energy density and lower proportions of protein, fiber, vitamins, and minerals (Campbell et al., 2021).

To help tackle obesity, nutrients linked with negative health effects such as sugar, fat, and salt can be reduced from ultra-processed foods in a process called "Food Reformulation" (Harastani et al., 2020). In the last decade, reformulation of the food supply is viewed as the best investment for preventing diet-related diseases and has been implemented in many countries (Grunseit et al., 2021). More recently, the focus of reformulation policies has shifted to added sugar and energy reduction, and sparse initiatives have been launched to increase the nutrient density of foods by increasing their amount of fiber, whole grains, or specific fats such as omega-3 (Gressier et al., 2020).

Food reformulation can have significant impacts on public health, but realizing this potential will require more clarity and consensus on the underlying notions and mechanisms by which reformulation can affect people's diets and health (Gressier et al., 2020). However, the daily intake of all unhealthy foods and nutrients still exceeds the recommended amount globally, coinciding with inadequate healthy food consumption (e.g., sugar-sweetened beverage consumption - SSB) (GBD 2017 Diet Collaborators, 2019). At the same time, nearly all healthful foods and nutrients are consumed in insufficient amounts globally.

Functional foods are a category of foods that are promoted as having health benefits (Urala & Lähteenmäki, 2007).Nowadays, the globally growing interest and acceptance of functional foods have a major impact on the market, and unlike decades ago, consumers are motivated and willing to consume functional foods (Kaur & Das, 2011). Foods that contain bioactive components are another interesting area for the food sector in obesity control (Binks, 2016). The potential synergy in formulations of foods containing anti-obesity bioactive food components attracts the attention of scientists (Kaur & Das, 2011). Obesity and many other chronic diseases are currently being discussed in relation to plant-derived antioxidants and their potential for prevention or even reversal (Deledda et al., 2021). Many antioxidant compounds have been examined and found to have anti-obesity, antioxidant, anti-dyslipidemia, and anti-diabetic potential (Khutami et al., 2022). Therefore, natural plant antioxidants could play important roles in controlling obesity, but well-designed clinical trials are necessary to better understand their effects (Pérez-Torres et al., 2021).

4. Implemented strategies and programs to promote healthier and more sustainable diets

A growing number of countries have developed strategies or action plans aimed at improving diet quality and reducing obesity prevalence (Roberto et al., 2015). Based on previous experiences and accumulated knowledge, it is evident that broader system-level, policy, and environmental strategies are required to achieve meaningful changes in dietary habits at both the individual and population levels (Mozaffarian et al., 2018)b.

4.1 Fiscal policy measures and taxation strategies

Fiscal policies represent one of the most widely implemented tools for the prevention of non-communicable diseases (NCDs). These include taxes (fiscal disincentives) on sugar-sweetened beverages (SSBs), unhealthy nutrients (saturated and trans fats, salt, sugar), and/or unhealthy foods (defined through nutrient profiling), as well as subsidies to promote the consumption of fruits, vegetables, and other healthy foods (WHO, 2016). The year 2016 has been referred to as "the year of the sugar tax" and currently more than 35 countries, states, and citieshave introduced some form of taxation on sugary beverages (Shahid & Bishop, 2019).

Evidence shows that increasing SSB taxes can lead to significant reductions in their purchase and consumption, resulting in health benefits and lower obesity prevalence — as demonstrated in Thailand (Phonsuk et al., 2021), Australia (Tangcharoensathien et al., 2019), Mexico and Chile (Fuster et al., 2020).Kaplan et al. (2024) reported that following the implementation of excise taxes on sugary beverages in five U.S. cities (Boulder, Philadelphia, Oakland, Seattle, and San Francisco), purchases declined significantly and continued to decrease over time.

4.2 Advertising regulation and front-of-package labeling

Advertising has a substantial impact on consumer behavior. Products most heavily advertised are often nutritionally poor and inconsistent with healthy dietary recommendations (Obesity Action Scotland, 2019). For example, according to Obesity Action Scotland, only 2.5% of annual food and drink advertising expenditures in 2017 were directed at fruits and vegetables, while 46% promoted confectionery, sweet and savory snacks, and soft drinks.

The widely used policy tool is ***front-of-package labeling***, which provides consumers with accessible information on products that can harm health, thereby guiding purchasing decisions (Dintrans et al., 2020; Osiac et al., 2018). This approach is simple, cost-effective, and increasingly adopted worldwide.Some countries are implementing more comprehensive strategies that combine multiple policy elements — such as taxation, advertising restrictions, labeling, and sales regulation in specific environments (e.g., schools). These integrated approaches are particularly effective in modifying food environments and consumer behavior, creating synergies between policy instruments.

4.3 Food waste reduction and circular economy solutions

A key component of sustainable food system transformation involves minimizing food waste along the entire supply chain (Campbell et al., 2017). Recycling and bioconversion of food waste offer promising strategies for sustainable development, enabling the conversion of waste materials through microbial fermentation into value-added products such as enzymes, food and feed additives, fertilizers, biofuels, animal feed, food-grade pigments, single-cell protein (SCP), and other valuable chemicals (Tropea et al., 2022).

Household food waste has also been used as a source for biogas production, which serves as renewable energy in transportation, such as biogas-powered buses (Liu et al., 2022). Effective waste reduction requires raising awareness among retailers and consumers about purchasing behaviors, challenging cultural norms and expectations, and, in some cases, revising relevant legislation (Guterres, 2019). Integrating environmental and nutritional information on food labels — with the latter already widespread — provides consumers with critical data to make informed choices (Bailey & Harper, 2015).The implemented strategies and programs clearly demonstrate that a combination of fiscal policies, regulatory measures,

and environmental interventions can effectively shape healthier and more sustainable food environments. However, the success of these interventions depends not only on their design and enforcement but also on continuous monitoring, evaluation, and adaptation to local contexts.

4. Future perspectives for sustainable and healthy food systems

Evidence consistently shows that healthy foods are relatively more expensive than unhealthy options, which creates a barrier for many consumers and widens nutritional inequalities (Abay et al., 2022; Kahan & Zvenyach, 2016; Hawkes et al., 2015). This gap represents an opportunity for governments and other stakeholders to intervene strategically. In particular, governments can implement fiscal measures that reduce the price gap between healthy and unhealthy foods by offering incentives to food producers and retailers to make healthier options more affordable. Additionally, policy-makers, local authorities, and political stakeholders have a crucial role in creating enabling environments that promote and encourage healthier choices at the population level (Kobes et al., 2022).

Tariff regulations may serve as powerful tools to discourage the consumption of unhealthy foods and to promote healthier alternatives (Abay et al., 2022). The food industry, in turn, should be further oriented toward food reformulation and the development of functional foods, ensuring healthier choices without compromising food safety. While reformulation can substantially improve the nutritional profile of foods, maintaining sensory attributes such as taste remains a major challenge (Shahid & Bishop, 2019).

The implementation of clear, easily recognizable food labeling systems for reformulated products could help consumers make informed decisions without the need for extensive label reading. A well-designed labeling strategy should be an integral part of broader nutrition policies, providing consumers with simple and practical information on products that may pose health risks and guiding healthier purchasing behaviors (Rosewarne et al., 2020).

Ultimately, integrated policies, strategic investments, and culturally sensitive approaches are essential to drive meaningful change across multiple sectors, including food production and manufacturing, workplaces, schools, healthcare systems, nutrition support programs, and research and innovation (Mozaffarian et al., 2018)b. Public–private partnerships and multisectoral collaboration are critical for achieving these goals.

Moreover, the agri-food sector remains one of the most important actors in this process. Strengthening its role in developing sustainable food systems can indirectly contribute to reducing obesity prevalence and diet-related NCDs while ensuring long-term environmental and economic sustainability.

5. Conclusions

The agri-food sector represents a pivotal actor in the transformation towards healthier and more sustainable food systems. Its involvement is crucial in developing, distributing, and marketing healthier food options that align with public health goals and environmental sustainability. Reformulation programs, aimed at improving the nutritional profile of foods while maintaining product quality and consumer acceptance, should be embedded within a comprehensive food and nutrition strategy. Such a strategy must be supported by strong governmental policies and public awareness campaigns that encourage healthier dietary behaviours and shift consumption patterns towards more sustainable and balanced diets (Rosewarne et al., 2020).

Given the increasing consumer interest and willingness to adopt functional foods (Kaur & Das, 2011) the integration of bioactive components into food products offers an additional, promising pathway for addressing obesity and related non-communicable diseases (Binks, 2016).

However, real and lasting change will require coordinated, multisectoral action involving governments, the private sector, academia, and civil society. Aligning health, agricultural, economic, and environmental goals will be key to ensuring that food system transformation leads to measurable health benefits, reduced disease burden, and improved population well-being.

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