Ultra processed foods consumption effects and industries initiatives for healthier food choices: a review

Aza Sherin Binti Mohamad Yusuff[1,*] and *Sharifudin* Bin Md Shaarani[2]

[1]Faculty of Medicine and Health Sciences, Universiti Sains Islam Malaysia, 71800 Nilai, Negeri Sembilan, Malaysia.

[2]Faculty of Food Science and Technology, Universiti Sains Islam Malaysia, 71800 Nilai, Negeri Sembilan, Malaysia.

Abstract. Ultra processed foods (UPFs) are dominating our food system and becoming staples across urban and rural settings, displacing traditional diets and whole foods. Increasing concern on these foods stems from their potential to promote addictive eating behaviors, hinder healthy weight management, and contribute to the global burden of non-communicable diseases (NCDs). Our aim is to conduct a review on the health impacts of UPFs and the various initiatives by food industries globally in producing 'healthier' UPFs. Evidence showed that high UPFs consumption was associated with an increased risk of all-cause mortality, overall cardiovascular diseases, other NCDs and adverse outcomes in the newborn. Reduced nutritional intake of minerals and vitamins from UPFs results in unbalanced meals which leads to micronutrient deficiencies throughout life stages. These risks accumulate across time and generations. Food processing industry plays a crucial role in shaping modern diets. They are taking some steps such as reformulating products to reduce specific ingredients like sugar, salt, and unhealthy fats, and are also focusing on portion sizes and packaging. Reliance on processed food and its effects on health demand innovative food products that can preserve nutrient density, reduce food additives and metabolic health effects that substitute UPFs with minimally processed and fiber-rich food that is truly healthy for the entire population.

1 Introduction

Ultra-processed foods (UPFs) are typically characterised as highly refined formulations of non-nutritive compounds containing elevated amounts of sugar, fat, sodium, food additives, and dietary emulsifiers [1] with hyper-palatability and undesirable nutritional profiles while being deficient in dietary fibre and essential micronutrients [2,3].

Over the past century, developments in food science and technology have had a significant impact on the evolution of the global food system [4]. This industrial development has not only produced a wealth of safe, convenient, and reasonably priced food items, but has also made ultra-processed foods (UPFs) more widely available and consumed [2,3,4]. These manufactured goods, which are made with largely industrial materials and undergo a lot of processing, have influenced and frequently control eating habits across the world. UPFs

*Corresponding author: azasherin@usim.edu.my

account for more than half of daily energy intake in several high-income countries, such as the US, Canada, and the UK, and their consumption is rapidly increasing in both low- and middle-income countries [2,3,5,6,7]. UPFs can make up about 60% of daily calories in the United States alone [8].

The widespread rise in UPF use has sparked intense discussion and raised serious debates about its significant effects on public health (2, 9]. Several studies, primarily observational and meta-analyses, have consistently linked high consumption of UPF to a wide range of negative health outcomes, prompting serious concerns regarding the inherent healthfulness of these foods and the industrial processes involved in their production [2,7,5,6,10]. According to critics, UPFs' unique characteristics such as their unbalanced nutritional profiles, changed physical structures, and the presence of different additives and possible contaminants, may work together to raise mortality rates and the incidence of chronic diseases [2,3,7]. Nonetheless, there is a continuous critical debate regarding whether the observed health harms are mainly caused by the industrial processing itself or are primarily a result of the generally unhealthy nutritional composition (such as high levels of fat, sugar, and salt) commonly present in these products [9,11,12,13,14]. According to some viewpoints, processing may even be advantageous [2].

This paper conducts a thorough analysis of the complex problems raised in the sources cited, methodically looking at the negative health impacts of consuming highly processed foods and the proactive steps the food industry has taken to promote healthier eating habits. It will methodically outline the definitions and objections to UPFs, examine the wide range of their health effects, investigate the intricate biological and behavioral mechanisms, and assess the various approaches including both industrial innovation and public policy interventions that are being sought to lessen their adverse effects and promote healthier eating habits.

2 Defining ultra-processed foods and associated criticisms

A key component of the current public health concern is the idea of ultra-processed foods (UPFs) linked to chronic diseases [15]. The NOVA system, developed by Brazilian researchers, is the most well-known and applied classification framework. NOVA classifies foods according to their nature, extent and purpose of industrial processing, in contrast to conventional categorization techniques that mostly concentrate on nutrient composition [5,11]. The NOVA food classification system's details and guiding principles were first published in 2009 [15].

2.1. The NOVA classification system: characteristics and examples

In the NOVA system, UPFs are specifically described as "formulations of ingredients, mostly of exclusive industrial use, typically created by a series of industrial techniques and processes" [5,6]. According to Mialon [39], they are defined as compounds made from foods and additives, with little to no intact (unprocessed or slightly processed) food. According to Dai et.al. [5] and McClements [2], these goods are designed for convenience and typically include little to no whole or intact ingredients. They differ from less processed categories due to the industrial nature of their ingredients (such as highly refined ingredients and several industrial processing procedures) [2] and processing techniques (such as extrusion, molding, and pre-frying). Proteins, carbohydrates, and fats interact during processing to change the

structural, nutritional, sensory, oral, and gastrointestinal characteristics of UPFs, which are generally compositionally complex materials [2].

Table 1. Food categories that are commonly acknowledged as UPFs

Food categories	Description
Beverages	Soft drinks, energy drinks, fruit-flavored milk drinks, various sweetened fruit drinks, and artificially sweetened beverages are all included in the broad category of beverages. These are frequently taken in large quantities and pose a serious risk because of their high sugar content and quick rates of consumption [2].
Baked goods	This category includes mass-produced, packaged baked goods such cakes, breads, buns, biscuits, cookies, and pastries. They are prepared to have a constant texture and a long shelf life, and they frequently contain a lot of industrial additives [2].
Snacks & confectionery	This category comprises a wide range of packaged candies, confections, savory and sweet snacks. Due to their high energy densities and hyperpalatable designs, these items may cause overconsumption [2,3].
Prepared meals	UPFs include a wide range of convenient meal options, including prepared meat products (e.g., fish nuggets, poultry nuggets, hot dogs, sausages, and other reconstituted meat products), frozen pizzas, instant noodles, and pre-packaged frozen dishes [2,6]. These frequently include chemicals to enhance shelf life, physicochemical characteristics, or sensory qualities [2].
Breakfast cereals	Due to their considerable processing and added sugars, sweetened breakfast cereals are usually included.
Other highly modified products	Margarine, some fruit yogurts, and other "diet" or "low-calorie" goods also meet the UPF requirements. It is important to note that fortification does not necessarily eliminate a product's ultra-processed nature, as products that are fortified with essential nutrients can still be categorized as UPFs if they meet the processing requirements [12,16]. More important than the final nutrient content is the extent and intent of processing [11].

2.2. Criticisms and controversies surrounding the UPF concept

The NOVA classification system and the more general notion of "ultra-processed foods" have been the subject of intense criticism and controversy, despite the fact that they have been widely adopted in research and policy discussions [4,9,11].

1. Ambiguity and imprecision in definition
   According to Lockyer et al. [9], the term "ultra-processed foods" is viewed as vague and ill-defined. It is claimed that the NOVA classification system is unclear and could cause

foods to be misclassified [17]. The NOVA system can be arbitrary and challenging to use consistently because it depends on the scope and intent of processing. Public comprehension and scientific replication may be hampered by the absence of clear, widely accepted standards [9,18].

2. Overemphasis on processing versus nutrient content
One of the main points of contention is whether the food's nutrient profile or the level of processing should be the main determinant for classification [4,9,11]. Critics contend that emphasizing processing in and of itself takes focus away from recognized links between nutrients and health. Regardless of the processing level, they argue that many of the negative health effects associated with UPFs can be simply explained by their generally high content of unhealthy nutrients (such as saturated fat, free sugars, and sodium) and low content of beneficial ones (such as fiber, protein, and micronutrients) [9,11,12]. Although NOVA is widely used in research, the Scientific Advisory Committee on Nutrition (SACN) recognized that it is still unknown if the processing or composition of these foods makes them intrinsically unhealthy [11].

3. Lack of clearly defined causal mechanisms
The perceived absence of well-defined biochemical or physiological pathways that directly connect processing in general to unfavorable health consequences, regardless of nutritional composition, is another important critique [9]. Critics contend that the exact mechanisms through which ultra-processing impacts bodily systems remain unclear, despite observational research demonstrating high correlations [4,9]. The idea that certain food processing methods are to blame for the observed connections is still in its early stages of investigation [4].

4. Misclassification of nutritious foods as UPFs
According to Lockyer et al. [9] and ATNi (Access to Nutrition initiative) [12], the NOVA system has been criticized for labeling some foods that are generally regarded as nutrient-dense or beneficial as UPFs, potentially causing "misalignment" with healthy dietary guidelines. Fortified breakfast cereals, some whole-grain breads, and some yogurts are a few examples [12,18]. In contrast to their animal-based counterparts, plant-based meat and dairy alternatives—which are frequently categorized as UPFs because of their industrial formulation—are emphasized as examples that can help reduce greenhouse gas emissions and are not always associated with negative health risks [35]. Customers and legislators may become confused by this and believe that the recommendation to stay away from all UPFs is ineffective [9].

5. Potential for unintended consequences in public health messaging
Advising people to "avoid all UPFs" may pose negative consequences, especially if they are vulnerable [9]. Even though they are categorized as UPFs, a lot of convenient and reasonably priced processed meals offer vital nutrients to people with little time, money, or access to cooking equipment. Strict advice to stay away from UPFs may worsen nutrient intakes for people who depend on these foods and cause shame and guilt. There was also discussion of the conflict between the UPF notion and contemporary approaches to public health improvement, such as reformulation [9]. Researchers generally agree that food processing has a substantial impact on diet quality and health outcomes, despite these criticisms, and that more research is necessary to fully comprehend these effects [4,11,17].

3 The consumption of ultra-processed foods and its impact on health

The increasing consumption of ultra-processed foods (UPFs) worldwide has caused considerable concern among the public health community, as they have been repeatedly linked to a variety of negative health outcomes [2,3,5,6,7]. UPFs have established themselves as a significant modifiable risk factor for chronic diseases and early death due to their extensive availability, active marketing, and intrinsic qualities [3,7].

3.1 Important health effects and results in high-income, developed nations

The highest levels of UPF consumption are generally found in developed countries, when intake frequently surpasses 50% of daily calorie intake [Adams & White, 2015; Juul et al., 2022; Scientific Advisory Committee on Nutrition (SACN), 2025]. In the US, the UK, and Canada, UPFs make up roughly 57.9%, 56.8%, and nearly 50% of total energy consumption, respectively [Juul et al., 2022; Nardocci et al., 2021]. A wide range of chronic non-communicable diseases (NCDs) are caused by this high, ongoing intake [Lane et al., 2024].

1. Cardiovascular disease (CVD) and mortality
   High UPF exposure is linked to higher risks of heart disease-related mortality, CVD events and mortality, and all-cause mortality (supported by both dose-response and non-dose-response analyses) [Dai et al., 2024; Lane et al., 2024; Taneri et al., 2022; Vitale et al., 2023].

2. Weight and metabolic outcomes
   There is strong evidence that excessive consumption is associated with overweight and obesity, including increased weight gain and BMI [Dai et al., 2024; Lane et al., 2024]. A higher incidence of Type 2 Diabetes, hypertension, Metabolic Syndrome, and hyperglycemia is also linked to UPF intake [Dai et al., 2024; Lane et al., 2024; Nardocci et al., 2021].

3. Organ and systemic health: Increased chances of cancer in general, particularly tumors of the central nervous system and prostate cancer, are among the adverse consequences [Dai et al., 2024; Lane et al., 2024]. Non-alcoholic fatty liver disease (NAFLD), inflammatory bowel disease, and signs of declining renal function are further related problems [Dai et al., 2024; Lane et al., 2024].

4. Mental health and aging: Consuming UPF is linked to markers of accelerated biological aging in individuals in the United States [Cardoso et al., 2024]. Risks of poor sleep outcomes and common mental disorders are additional correlations [Dai et al., 2024; Lane et al., 2024].

In addition to inadequate nutritional profiles, non-nutritional elements included in industrial processing and packaging are implicated in negative consequences [Elizabeth et al., 2020]. The formation of potentially hazardous substances like Advanced Glycation End-products (AGEs) during manufacturing, the displacement of healthier whole foods, high energy density, and the leaching of endocrine modulating chemicals like phthalates and bisphenols from packaging materials are some of these mechanisms [Elizabeth et al., 2020; Kadac-Czapska et al., 2023; Lane et al., 2024; Tumu et al., 2023].

3.2 Important health effects and difficulties in low and middle-income developing nations

Although consumption as a percentage of calories may be lower (e.g., 16% in Colombia vs. 30% in Mexico), UPFs are becoming more prevalent in the food chain in Low- and Middle-Income Countries (LMICs) [Popkin et al., 2021]. The primary issue is the growing exposure to UPFs, which contributes to the "double burden of malnutrition"—the co-occurrence of undernutrition and the sharp rise in obesity and non-communicable diseases [Popkin et al., 2020; Popkin et al., 2021].

1. Accelerating NCD epidemic: Nutrition-related NCDs such as diabetes, hypertension, coronary heart disease, and cancer are on the rise in LMICs due to fast rising consumption [Popkin et al., 2021]. Poorer and rural population segments are seen to have a greater burden of overweight and obesity [Popkin et al., 2020].

2. Industry vulnerability: The LMIC environment is distinguished by its susceptibility to aggressive industry influence [Mialon & Gomes, 2019; Lara-Mejía et al., 2025]. The UPF industry opposes effective public health measures through Corporate Political Activity (CPA), particularly in Latin America and the Caribbean (LAC) [Lara-Mejía et al., 2025; Mialon & Gomes, 2019; World Heart Federation, 2020]. CPA strategies include campaigning to overturn the requirement for food labelling on the front of the package and the taxing of beverages with added sugar [Lara-Mejía et al., 2025]. By focusing on personal physical activity instead of the part UPFs play in NCDs, the industry also aims to influence public opinion [Lauber, 2022].

3. Policy initiatives: In an effort to mitigate these impacts, LMICs are enacting or contemplating policies such as taxes on processed and red meat, which have been examined in countries like Mexico [Connors et al., 2025; Valizadeh & Ng, 2024]. Mandatory front-of-pack labelling laws are promoted in India [Sharma et al., 2024].

4. Reformulation and sustainability issues: Although food reformulation may enhance UPFs [McClements, 2024], complicated procedures such as food matrix restructuring are difficult to apply in developing nations properly [Onyeaka et al., 2023]. Additionally, high water consumption and resource strain in the Global South are two ways that the UPF production model contributes to environmental deterioration [Clark et al., 2019; Leite et al., 2022].

3.3. Effects on overall health and Non-Communicable Diseases (NCDs)

A significant and expanding amount of data, mostly from large observational studies and strong meta-analyses, has demonstrated a clear and alarming correlation between higher UPF intake and a higher risk for many NCDs [2, 5,6,7]. Direct correlations between UPF exposure and 32 (71%) different health parameters were found by an umbrella review that synthesized results from several meta-analyses. These parameters covered important areas like mortality, different types of cancer, mental health, respiratory disorders, cardiovascular health, gastrointestinal function, and metabolic health outcomes [5, 7, 20]. These results highlight the wide-ranging systemic effects of UPFs on human health and physiology.

3.1.1. Obesity and weight gain

The association between UPF consumption and obesity, as well as unintended weight gain, is one of the strongest and most frequently documented associations between UPF consumption and health [2,3,5,6,7,18,19]. Higher UPF intake is significantly positively associated with an increased risk of overweight and obesity in systematic reviews and meta-analyses of observational studies [6,18,21]. High UPF intake was consistently linked to a 32% higher risk of obesity in one meta-analysis that focused on prospective cohort studies [18].

When compared to an unprocessed diet, an ad libitum UPF-rich diet resulted in a measurable increase in calorie intake and consequent weight gain, according to crucial experimental evidence from a pivotal randomized controlled trial conducted by Hall et al. [22]. Interestingly, this impact remained even when the meals were carefully matched for fibre, sugar, sodium, total calories, and macronutrients. According to this, UPFs' unique qualities, which go beyond their direct nutritional makeup, may increase the risk of obesity by encouraging overeating, at least temporarily [2,7].

3.1.2. Cardiometabolic health (diabetes, hypertension, dyslipidemia, cardiovascular diseases)

The global burden of non-communicable diseases is greatly increased by UPFs, which are strongly linked to a wide range of cardiometabolic risks [3,5,7,18,19].

1. Type 2 diabetes: According to some studies, there is a consistent and significant correlation between high UPF consumption and an increased risk of type 2 diabetes. [2, 5, 7,18, 23]. This risk was measured by one meta-analysis, which found that consuming a lot of UPF increased the risk of diabetes by 37% [18]. Weight growth accounts for most, but not all, of this connection [4].

2. Hypertension (high blood pressure): High UPF intake has been linked to an increased risk of hypertension [2,5,6,7,18,19]. According to a meta-analysis, people who consume a lot of UPF had a 32% higher chance of developing hypertension [18].
3. Dyslipidemia (abnormal levels of cholesterol and lipids): A high consumption of UPFs in the diet is associated with a higher risk of developing dyslipidaemia in its different forms [7,18]. In particular, a meta-analysis revealed a 43% increased risk of low HDL cholesterol concentration (commonly referred to as "good" cholesterol) and a 47% increased risk of hypertriglyceridemia (high triglycerides) [18]. This is also mentioned in another study [6].

4. Cardiovascular diseases (CVD): Consuming UPF has been linked to a higher risk of cardiovascular diseases in general, including cerebrovascular disease (stroke) and cardiovascular-related death, according to consistent and alarming data [6, 7]. High UPF intake was linked to a 29% higher risk of CVD, according to a systematic review and meta-analysis [10]. Additionally, research indicates heightened exposure to substances such as bisphenol A/S and acrolein, which have been connected to cardiometabolic illnesses [2, 7]. According to one review, UPF use is linked to metabolic syndrome [18].

3.1.3. Cancer

Breast, prostate, and colorectal cancers are among the specific types of cancer for which UPF consumption has been linked to an elevated risk [6,7, 25]. Convincing evidence of a correlation with overall cancer risk was found in an umbrella review [7]. Also regarded as "possibly carcinogenic to humans" are non-sugar sweeteners, which are frequently present in UPFs [7].

3.1.4. Mental health beyond physical health

UPF intake has been associated with negative outcomes related to mental health, such as a potential correlation with incidents of anxiety and depressive symptoms, as well as more general outcomes related to common mental disorders [7, 8].

3.1.5. Other significant health outcomes

High UPF intake has detrimental effects on health in several other important domains, including:

a. Biological aging: Consuming more UPF may hasten cellular aging processes, according to a cross-sectional study that discovered a troubling correlation between the two [26].

b. Frailty: High use of UPF is associated with a higher risk of frailty incidence in older persons, a condition that makes them more susceptible to negative health consequences [15].

c. Respiratory conditions: Consuming UPF has been linked to wheezing and asthma in children and adolescents, suggesting a possible influence on respiratory health from an early age [5, 6,7].

d. Renal function decline: There is strong evidence linking UPF use to a loss in renal function, highlighting its systemic effects on important organs [5].

e. Non-alcoholic fatty liver disease (NAFLD): According to Henney et. al [27], UPF use has been particularly linked to NAFLD characteristics.

f. Gastrointestinal health**:** According to Lane et. al [7] and Pagliai et. al. [6], UPFs are also associated with a higher risk of inflammatory bowel illnesses and functional gastrointestinal disorders, such as irritable bowel syndrome (IBS).

3.2. Specific UPFs subgroups and all-cause mortality

Analyses of particular UPF subgroups have revealed unique associations with all-cause mortality, highlighting the heterogeneity of these products even though the general classification of UPFs presents a troubling overall picture ([28].

1. Overall UPFs**:** All-cause mortality risk is considerably higher for those who consume the most UPF than those who consume the least (RR = 1.29, 95% CI: 1.17, 1.42) with a median follow-up of 9.05 years with 110,721 individuals and 5,044 deaths overall, this was generated from 5 distinct research [28].

2. Sugar-sweetened beverages (SSBs): With a Relative Risk (RR) of 1.11 (95% CI: 1.04, 1.18), high consumption of sugar-sweetened beverages (SSBs) is consistently linked to an increased risk of all-cause mortality [5, 28].

3. Artificially sweetened beverages (ASBs): Although ASBs are frequently promoted as healthier substitutes, they are also associated with a higher risk of all-cause mortality. The studies [5, 28] reported that the RR for high versus low consumption of ASBs is 1.14 (95% CI: 1.05, 1.22).

4. Processed meat and processed red meat: There is a definite correlation between processed meat and processed red meat and higher all-cause mortality [28]. The RR for high intake of processed meat is 1.15 (95% CI: 1.10, 1.21), while the RR for processed red meat is even higher at 1.19 (95% CI: 1.11, 1.27).

5. Breakfast cereals: It's interesting to note that some research has produced contradictory results on breakfast cereals. High consumption of breakfast cereals, especially whole grain cereals (RR = 0.77, 95% CI: 0.72, 0.81), was associated with a lower mortality risk (RR = 0.85, 95% CI: 0.79, 0.92), according to a meta-analysis ([28]. The complexity and heterogeneity present in the broad UPF category are highlighted by this particular discovery, which implies that categorical condemnations of all UPFs may oversimplify their varied health effects [5, 7, 29].

3.3. Hypothesized mechanisms of adverse health effects

UPFs have a variety of direct and indirect pathways that contribute to their complex and multidimensional detrimental health consequences.

1. Poor nutritional profile
   Many UPFs have an intrinsically poor nutritional profile, which is a major and well acknowledged mechanism [2,3,4,7]. While they are significantly low in vital dietary fiber, protein, and other micronutrients, they are frequently high in energy density, added sugars, unhealthy saturated and trans fats, and sodium [2,3,4,7,10]. Obesity, metabolic dysfunction, and other NCDs are directly caused by this dietary imbalance [3, 4].

2. Displacement of whole and minimally processed foods
   More nutrient-dense whole and minimally processed foods (such as fruits, vegetables, whole grains, nuts, and seeds) are frequently displaced from the typical dietary pattern

by a diet high in UPFs [2,3,4,7]. As a result, less healthy bioactive substances are consumed, including phytoestrogens and polyphenols, which are essential for preventing illness and maintaining general health [7].

3. Promotion of overeating and hyperpalatability
   UPFs are carefully designed to be extremely rewarding and hyperpalatable [2, 3]. According to several sources [2,3,7,31,32] their enticing sensory qualities (such as texture and flavor) can encourage faster eating rates and a decreased satiety and satiation response, resulting in unintentional overconsumption. Higher total calorie consumption and consequent weight increase are greatly influenced by this [2,3,7].

4. Altered food matrix and rapid digestion
   The natural food matrix may be significantly changed by the extensive processing required to produce UPF [2,3,4,7]. This structural change may affect the way foods are absorbed, processed, and interact with satiety-related gut-brain signalling pathways [2,7]. High glycaemic loads and potentially harmful metabolic reactions, like postprandial glycaemic spikes, are caused by UPFs' frequent design for quick intake and digestion [7].

5. Industrial food additives
   Another theory for the detrimental health consequences of UPFs is the widespread use of several industrial food additives [3, 7].

   a. Non-sugar sweeteners (NSS): These are commonly used to lower calorie intake without sacrificing sweetness. However, new research indicates that NSS may have a negative impact on the gut microbiota, which could increase the risk of cardiometabolic disorders and cause glucose intolerance [7,18]. The International Agency for Research on Cancer has designated aspartame in particular as "possibly carcinogenic to humans" [7].
   b. Emulsifiers: According to Lane et al [7], emulsifiers and other additives are associated with dysbiosis of the gut microbiota and increased intestinal permeability, both of which can exacerbate chronic inflammatory responses.
   c. "Cocktail effects": Exposure to mixtures of several chemicals may have more detrimental effects on human health than exposure to a single additive, raising concerns about the possible "cocktail effects" [7].

6. Toxic reaction products from processing
   Highly processed industrial foods, especially those that are heated for extended periods of time or at high temperatures, can produce potentially hazardous compounds that are absent from minimally processed foods [2,3,7]. These consist of:
   a. Advanced glycation end products (AGEs): Because of extensive food processing and extended heating, UPFs are especially vulnerable to the creation of AGEs. High levels of AGEs have been associated with cancer, neurological disorders, and chronic inflammatory diseases [2].
   b. Acrylamide and acrolein: According to Lane et al. [15] and the Global Food Research Programme [3], compounds such as acrylamide and acrolein have been linked to higher risks of cardiovascular disease and cancer, respectively.
   c. Industrial trans-fatty acids and heterocyclic amino acids are other recognized byproducts of specific processing techniques that have been connected to health issues [3,7].

7. Packing contaminants
   According to some studies and reports, UPFs may act as carriers of pollutants that leak into food from packing materials [2,3,7]. These consist of microplastics, phthalates, and bisphenols (e.g., BPA, BPS) [7]. These substances have been linked to an increase in cardiometabolic illnesses and other detrimental health effects, and they frequently affect hormones [7].

3.4. The impact of UPF consumption disparities on vulnerable populations

The impact is exacerbated by the unequal distribution of the social burden of UPF consumption. Research demonstrates a distinct socioeconomic disparity in UPF consumption, with younger generations, those with lower socioeconomic status (SES), and urban people generally having higher intake levels [7, 33]. To illustrate notable geographical and demographic differences, the average UPF consumption in Europe is 27% of total daily energy intake; however, this varies significantly, ranging from 14% in Italy and Romania to 44% in the UK and Sweden [33]. UPFs make up 16% to 30% of total energy consumption in low- and middle-income nations like Mexico and Colombia, respectively [7]. In order to address public health disparities, focused and equitable policy interventions are desperately needed, as evidenced by the disproportionate consumption among vulnerable populations [7, 33].

4 Industry initiatives for healthier food choices

Despite the serious concerns about UPFs, the food industry has started to investigate and put into practice initiatives to make their products healthier and more sustainable [2, 4]. This entails moving away from concentrating only on safety, shelf-life, and palatability and toward a more comprehensive assessment of environmental impact and health potential [4]. The main contention is that many UPFs may be able to be reformulated and reengineered to increase their sustainability and healthiness; however, this still has to be demonstrated through thorough scientific research [2].

4.1. Reformulation and reengineering of UPFs

The idea that many of these products can be reformulated and reengineered to greatly improve their sustainability and healthiness profile is a fundamental component in tackling the UPF challenges [2,44]. Important reformulation techniques include:

i. Reducing unhealthy nutrients and energy density
   One basic strategy is to reduce the overall energy density of UPFs by reducing the total amounts of digestible fats, proteins, and carbohydrates (particularly refined sugars and starches) [2,3]. Reducing trans fats, saturated fats, free sugars, and sodium (salt) is a consistent goal of specific reformulation projects [2,44,45]. For instance, action plans

aimed at lowering total fat, trans fatty acids (TFAs), and saturated fatty acids (SFAs) as well as correcting imbalanced n-6/n-3 ratios are developed using thorough assessments of the fatty acid profiles of processed meat products [44].

ii. Balancing nutritional profile and fortification
By adding advantageous nutrients, strategies also seek to improve the total nutritional value [2]. This entails substituting healthier products for less appealing ones and fortifying with dietary fiber, vitamins, and minerals [2]. To avoid a "health halo" effect, wherein additional nutrients could unintentionally justify the purchase of otherwise unhealthy items, this must be done carefully [16]. One effective strategy to reduce overeating and prevent weight gain is to reformulate UPFs to improve their ability to promote satiety and satiation [2,7]. This involves creating meals that naturally lower total caloric consumption by fostering feelings of fullness and contentment [2].

iii. Modulating mastication and digestion
The physical structure of UPFs can be reengineered using sophisticated food engineering techniques [2]. This may affect gastrointestinal activity and oral processing, which may then affect nutrient release, absorption rates, and eventually metabolic responses and satiety signals [2,7].

iv. Precision processing
Careful modification of constituent qualities and their interactions is made possible by the use of precise and regulated processing processes. This makes it possible to optimize UPFs' nutritional and functional qualities, resulting in products that are intended to achieve particular health goals [2].

v. Sector-Specific Reformulation Initiatives

Various UPF categories are undergoing exploration and implementation of reformulation projects.

i. Fruit juices: Fruit juices have some nutritional fiber and phytochemicals, although they are often heavy in calories and sweets. Mitigation measures to lower juice sugar concentration while maintaining desired sensory qualities are still being researched [2].
ii. Baked foods: Lowering the amount of fat, sugar, and salt in pastries and other mass-produced foods is one way to make baked goods healthier [2].
iii. Snacks: The main goal of reformulation efforts for snacks is to reduce their energy density. Moderation is crucial because overindulging in any snack, even one with a lower energy density, can result in health issues [2].
iv. Reconstituted meats and meat substitutes: According to McClements [2], these goods frequently have excessive fat, salt, sugar, starch, and additive contents. Adjusting their composition to lower SFAs and TFAs and improving processing techniques are two ways to increase their healthiness [44].
v. Spreads, dressings, and sauces: These everyday condiments frequently lead to a diet rich in fat, sugar, and salt. Reducing their less desirable components is another use for reformulation attempts [2].

4 .2. Innovative paradigms and the "Metabolic Matrix"

In addition to incremental reformulation, a more revolutionary strategy known as the "Metabolic Matrix" is being suggested [34]. By concentrating on how food products' structure and components interact with and affect basic metabolic processes mediated by the gut, liver, and brain, this paradigm seeks to strategically design food items. By maximizing the metabolic reactions to food, this strategy aims to avoid illness and promote general health [34].

The creation of completely new paradigms for food evaluation and assessment provides a larger framework for such innovation [4]. With the use of cutting-edge technology like digital tools and artificial intelligence, these upcoming paradigms are expected to be based on innovative pillars such as ergonomics, signalling, and precision nutrition [4]. The goal of this integrated approach is to create new food classification schemes that consider processing factors and nutritional content in a comprehensive manner [4]. Inspired by nature, biomimetics presents a viable avenue for creating food matrices and structures that resemble nature; this frequently calls for a blend of cutting-edge technology to promote health and wellbeing [4].

4.3. Integrating sustainability and environmental impact

The twin objectives of sustainability and health are driving more and more modern industry activities [2,3,4]. A concentrated effort is being made to improve the food supply chain's overall sustainability and lessen its detrimental environmental impact [2,4]. This includes:

1. Sustainable sourcing: Using ingredients with a reduced lifetime environmental impact while creating UPFs [2].
2. Circular economy principles: Adopting procedures that reduce waste and value food processing by-products to promote a more resource-efficient and circular economy [4].
3. Plant-based innovations: Although they frequently fall under the UPF category, the creation of plant-based meat and dairy alternatives is a major step in the direction of sustainability because they usually use less water and produce fewer greenhouse gas emissions than their animal-based counterparts [35]. Emissions from land usage and agriculture greatly surpass the environmental impact of these items' supply chain.

4.4. Key challenges for industry initiatives

In spite of these encouraging trends, the food sector still has a lot of obstacles to overcome in order to put healthier and more sustainable ideas into action:

i. Maintaining desirable attributes and cost-effectiveness: Preserving the desired physicochemical, functional, and sensory qualities (taste, texture, and appearance) of food products without raising their price is a major challenge in reformulation [2, 42]. Despite its nutritional benefits, a "healthier" food product won't be accepted by consumers if it isn't tasty, practical, and reasonably priced [2].

ii. Limited long-term health investigations**:** Robust, long-term human clinical investigations that are explicitly intended to evaluate the health consequences of reformulated UPFs are severely lacking. It is challenging to conclusively demonstrate the effectiveness of many industrial health-oriented developments due to this dearth of evidence [2,9].

iii. Consumer perception and confusion**:** The definition and implications of "ultra-processed foods" are often unclear to consumers, which presents a significant challenge [9,42]. It can be challenging for consumers to distinguish between products that are truly improved and those that are just making flimsy "health claims" because they frequently rely on basic packaging cues to determine healthfulness [42]. In order to effectively communicate product features without increasing consumer confusion, it is imperative that labeling techniques be transparent, unambiguous, and relevant [42].

5 Regulatory and policy initiatives for healthier food choices

Governments and public health organizations around the world are pushing for and enacting regulations to lower UPF consumption and encourage healthier eating in light of the growing body of evidence showing negative health effects [3,7,16].

5.1. Policy strategies to reduce UPF consumption

A comprehensive strategy is considered required, combining several policy instruments to affect industrial practices and consumer behavior [3,16,36].

1. Front-of-pack labeling (FOPL) systems
   These systems are designed to assist customers in rapidly and simply determining the nutritional quality of packaged foods [36,42]. There are requests for UPFs to have particular warning labels indicating that they are ultra-processed or high in vital nutrients, even if the majority of FOPL systems are based on nutritional content [3,36]. Some nations, such as Chile, already impose levies on sugar-sweetened beverages and mandate warning labels on some highly processed foods [7,16,37]. In order to prevent consumer bias and guarantee successful implementation, the World Heart Federation (WHF) advises that FOPL systems be in line with national public health policy, make it simple to identify goods that are excessive in essential nutrients, and be mandatory to avoid consumer bias and ensure effective implementation [36]. It has been demonstrated that warning labels are useful for assisting customers in promptly and accurately identifying these kinds of products [36].

2. Taxes on unhealthy UPFs
   More than 45 nations impose taxes on sugar-sweetened drinks (SSBs), and some have also imposed fees on snacks and other UPFs [16,37]. National taxes on unhealthy UPFs and beverages may encourage people to choose healthier foods, particularly those in low-income households, according to research [16,37]. Mexican examples show that SSB taxes have a long-lasting effect on consumers [16].

3. Minimally processed food subsidies
   In addition to taxes, policymakers might provide targeted subsidies for less processed foods, especially for low-income groups, such as whole grains, fruits, vegetables, and legumes [3,37].

4. Marketing restrictions
   One important policy measure is to restrict the marketing and advertising of UPFs, particularly to children and adolescents [3,15,16]. It has been demonstrated that intensive marketing strategies encourage overconsumption [15].

5. School food policies
   Dietary practices can be greatly impacted by creating effective school feeding policies and establishing nutrition standards for procurement in educational institutions, childcare centers, jails, and other public settings [3,16,38]. For instance, healthier cafeteria lunches can be achieved by altering the way food is prepared in schools [38].

5.2. The crucial role of nutrient profiling models (NPMs)

Properly constructed NPMs can be used to harmonize various rules and are crucial in identifying which foods and beverages should be regulated [3]. Being the first to include measures that specifically capture UPFs—not just based on nutrient thresholds, but also by designating products with any quantity of non-sugar sweeteners as UPFs to be regulated—the Pan American Health Organization (PAHO) NPM is noteworthy [3]. This helps avoid unforeseen outcomes where policies may lower sugar intake without lowering consumption of ultra-processed beverages overall [3].

5.3. Corporate political activity and industry influence on policy

The food industry has shaped food environments for a long time, and its CPA can hinder the creation and execution of public health policies [3,16,39]. CPA tactics include:

1. Information & messaging: Spreading messages and information that could support and justify the use of UPF, which could displace whole foods and cause health issues [2].
2. Financial incentives: According to Popkin et al. [16] and Mialon & Gomes [39] offering financial incentives, such as sponsoring research and lobbying efforts, may be interpreted as compromising scientific integrity.
3. Constituency building and policy substitution: Establishing support among stakeholders and putting up substitute policies that might be less successful in resolving public health issues are known as constituency building and policy substitution [16,39].
4. Legal strategies: Using legal challenges to challenge rules is one of the legal strategies [39].

The WHO is creating mechanisms to protect against the "undue influence" of the UPF business [16, 39]. Governments are in charge of creating FOPL systems, allowing for public participation while maintaining transparency, independence, and rigor [36]. Although industry partners are frequently involved in medical research, the public frequently views

this as a source of bias for the research's integrity, especially in food and nutrition research [4].

6 Challenges, Criticisms, and Future Directions

Despite the increasing amount of data, there are still a lot of problems and objections to the comprehension and reduction of the consequences of UPF use [4,7,9,18].

6.1. Methodological restrictions and ongoing research deficits

1. Lack of defined classification**:** According to some authors [5,7,18,28], one of the primary research limitations is the absence of defined techniques for UPF classification. It is challenging to draw reliable conclusions and compare results from different research due to variations in the definition of UPF consumption (e.g., grams per day, percentage of energy, and proportion of total dietary weight) and the absence of standardization for high or low exposure values [18].

2. Inconsistent confounder accounting: Research frequently fails to take into consideration significant variables that could skew associations with health outcomes, such as socioeconomic status, body mass index, total energy intake, and overall nutritional intake [7, 11].

3. Limited causal evidence from RCTs**:** RCTs that directly examine the long-term effects of UPFs on hard disease endpoints (such as cancer or cardiovascular disease) are either impractical or ethically problematic, even though observational studies show strong associations [7,9,10]. Intermediate outcomes, such as body weight, insulin resistance, gut microbiota, and inflammation, can be evaluated in short-term trials [7].

4. Heterogeneity within UPF Categories**:** According to Veronese et al. [18], Lane et. al. [7] and ATNi [12], the UPF category itself is extremely diverse, encompassing a range of products such as processed meats, soft drinks, and some fortified cereals or yogurts that may have varying health effects. This complexity is shown by several research that reveal inverse relationships for specific UPF subsets (e.g., breakfast cereals) [28]. Given that not all UPFs are created equal, this has led to calls for cutting-edge research and policies that strike a balance between nutrition security and health [29].

6.2. Consumer confusion and public health messaging

Consumers are frequently perplexed by the term "ultra-processed foods," which hinders their ability to make informed choices [2,9,42]. When "health claims" on UPF packaging conceal substantial processing, it can be deceptive to rely solely on basic packaging cues [42]. This confusion may be reduced by including UPF information into current labeling systems and implementing public education campaigns [42]. Nonetheless, there is continuous discussion

regarding whether dietary guidelines should emphasize nutrient-based messages or the UPF concept, especially in light of worries that stigmatizing all UPFs may discourage vulnerable groups from consuming inexpensive, nutrient-dense processed foods [9].

6.3. Suggestions for upcoming studies and policies

1. Urgent mechanistic research: to know the precise biological mechanisms through which UPFs affect health and to determine the best means of reducing and controlling ultra-processing, more research is required [4,7,40]. investigating how particular ingredients, processing methods, and additives affect the food matrix, gut microbiota, and metabolic reactions is one way to do this [4,7].

2. Development of comprehensive policies: to lower dietary exposure to UPFs, governments must create and assess comprehensive, population-based public health initiatives [7,16,41]. these should consist of dietary recommendations and policy frameworks that specifically target UPFs [7,16]. since brazil's 2014 dietary guidelines, the phrase and related suggestions have already been adopted by seven nations [7].

3. Holistic food evaluation systems: new systems for classifying and evaluating foods are required, ones that consider all aspects of processing, as well as elements pertaining to diet and food personalization, sustainability, and the circular economy [4]. to prevent biased research, this necessitates interdisciplinary partnerships and open innovation between academia and industry, with a strong focus on social responsibility [4].

4. Addressing access and food insecurity: policies should support initiatives that make natural, healthful, or minimally processed foods more widely available, valued, and reasonably priced, particularly for disadvantaged populations [3,9,10]. This is especially crucial in situations where access to nutrient-dense meals is restricted or non-existent [10].

5. Standardized research methodologies**:** To enable more precise evaluation of health effects and improved dose-response analysis, future research should strive for standardized methods in UPF categorization, such as defining food classes, nutrient composition, and particular processes or additives used in their production [5,18,28].

7 Conclusion

Consistent evidence has linked the global increase in consumption of ultra-processed foods to a number of negative outcomes, such as obesity, type 2 diabetes, cardiovascular diseases, cancers, mental health disorders, and increased mortality. This is a serious public health concern. These negative consequences are caused by the intricate interactions between UPFs' nutritional profiles, physical attributes, additives, and environmental pollutants.

As a result, businesses are concentrating more on reengineering and reformulation techniques to produce healthier and more sustainable products by lowering toxic ingredients, increasing nutritional content, and minimizing environmental impact. Innovative processing technologies and ideas like the "Metabolic Matrix" offer encouraging paths. At the same

time, public health organizations are pushing for strong legislative measures, such as comprehensive marketing restrictions, taxing unhealthy up providing subsidies for minimally processed alternatives, and clearly labeling products on the front of the package.

Definitional ambiguities, consumer confusion, and the strong influence of corporate political activity are some of the obstacles that stand in the way of progress. Urgent, multidisciplinary research is required for future advancement in order to standardize UPF assessment procedures, clarify causative pathways, and support evidence-based policy. Fostering moral partnerships between academia and business, maintaining open lines of communication, and creating comprehensive food systems that put sustainability and health first for all populations, especially vulnerable ones, must be given top priority. It might be feasible to lessen the negative consequences of UPFs and influence global dietary trends toward more sustainable, equitable, and healthful options by carefully fusing industrial innovation with effective public health regulations.

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