Proceedings of ICEGEE 2025 Symposium: Sensor Technology and Multimodal Data Analysis
DOI: 10.54254/2753-8818/2025.AU23542

Research Progress: The Ultra-Processed Foods Contribute to Micronutrient Deficiencies in Modern Diets

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Abstract: Micronutrient deficiency, commonly known as Hidden Hunger, has raised significant discussion in recent years, affecting more than 2 billion people worldwide. This review examines how Ultra-processed Foods (UPFs) amplify such deficiencies in modern diets. Characterized by industrial formulations and complex processing methods, UPFs are rich in additives but poor in essential vitamins and minerals. Their growing dominance in contemporary food systems can be associated with their convenience, affordability, and palatability. However, the extensive processing methods used in their production strip them of their natural nutritional values while integrating excessive processed sugars, fats, and sodium, contributing to the global burden of nutritional imbalances. Epidemiological studies have highlighted a distinct association between a high UPF-composed diet and increased risk of obesity, cardiovascular diseases, metabolic syndromes, and micronutrient deficiencies, posing threats, particularly among vulnerable populations. Mainstream methods currently used to tackle hidden hunger include fortification and supplementation, yet these measures fail to replicate the synergistic benefits of the consumption of whole foods. This review underscores the urgent need for multifaceted interventions through national and global policies, including taxation, market restriction, and promotion of educational programs, ultimately in hopes of reducing UPF reliance and promoting dietary diversity and equality. To align with Sustainable Development Goals, global cooperation is needed to address Hidden Hunger and ensure equitable access to unprocessed or minimally processed food.

Keywords: Ultra-processed food, hidden hunger, micronutrient deficiency.

1. Introduction

The crucial role micronutrients play in diets tends to be overseen by most. Micronutrients perform an essential range of functions that enable the body to produce hormones and enzymes and allow the body to tackle diseases efficiently and effectively. Affecting an estimated 2 billion people worldwide, micronutrient deficiencies, especially iron, vitamin A, zinc, iodine, and folate, are found to be most prevalent [1]. Deficiencies in such micronutrients can lead to serious health problems and were found to be major contributors to infections and associated with severe illness and death. Deficiencies in crucial micronutrients may result in anemia, brain damage, increased risk of chronic diseases, and weakened immune systems. In pregnant women, severe iodine deficiencies can result in stillbirth, spontaneous abortion, and congenital anomalies, as well as reduced intellectual capacity [2]. In children, deficiencies in vitamin A may increase the risk of disease and death from severe infections such as diarrheal disease and measles [2].

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Aside from consisting of adequate amounts of crucial macronutrients, a balanced and healthy diet should consist of a wide array of micronutrients, including vitamins A, C, D, and B vitamins. Minerals that aid essential bodily functions include calcium, magnesium, iron, and iodine. Unlike macronutrients, micronutrients are only needed in small quantities, yet they are crucial for the body. Aside from supplements, a diet that provides sufficient and balanced micronutrients must include a variety of dietary sources. Healthy diets limit consumption of saturated and trans fats, sodium, and added sugars while emphasizing a low dietary portion of processed foods.

Excessive studies have been conducted to show the health benefits associated with plant-derived foods such as fruits, vegetables, whole grains, and legumes. However, globalization and urbanization have played a defining role in changing dietary habits, especially when it comes to the growing consumption of ultra-processed food (UPF) worldwide. Defined by the NOVA food classification system, UPFs are industrially manufactured products containing little to no whole foods and characterized by cosmetic alterations and additives that increase their palatability and sensorial properties [3]. Aside from their palatability, these energy-dense but nutrient-poor food-manufactured food items are recognized to be more convenient, economically friendly, and unprocessed food. Nutritional transitions of an increase in UPF consumption are associated with the modern lifestyle and can be explained by habitual changes, including increased portion sizes, snacking frequency, and the tendency to eat outside. Economic factors like inflation and rising labor costs have also come into play through increased dining prices, a quickened pace of life, and increased rent prices, where many find themselves in homes without a kitchen. The economic affordability, availability, and increased shelf-life also contribute to the major nutritional transitions that have taken place worldwide.

It has been well established through longitudinal and cross-sectional studies throughout the years that the increase in UPF consumption has been strongly associated with increased body mass index, waist circumference, and metabolic syndromes, explaining the prevalence of obesity and diabetes type 2 in modern society [4]. An increase in UPF consumption has also been shown to increase overall cancer risks and cardiovascular risks, two of the top causes of mortality shared across developed countries like the US and less developed countries like Madagascar [5]. These findings can be explained by the NOVA classification system, as UPFs generally tend to be higher in added sugars, fat, or sodium, in addition to containing additives and preservatives. These mechanisms explain the adverse health implications aforementioned.

Commonly known as Hidden Hunger, these UPFs are energy-dense and high in calories while lagging in crucial micronutrients. The nutritional composition of UPFs, due to complicated processing methods associated with their production, has led to a decrease in their micronutrient values. Numerous studies have been conducted on the relationship between UPF consumption and obesity and cardiovascular and cancer risks. The SENDO project [6] has concluded that a diet composed largely of UPFs is associated with an increased risk of micronutrient indecency through the investigation of children from the Mediterranean area. This review will contribute through a cross-analysis of the magnitude of the risk of micronutrient deficiency associated with UPF consumption. The ingredients, processing methods, nutritional values of UPFs, and health implications associated with micronutrient deficiencies will also be explored in deeper depth throughout the entirety of this review.

2. UPF in the modern society

The NOVA classification system categorizes UPFs as industrial formulations synthesized in laboratories made for commercial retailing made mostly from food constituents or substances extracted from food. Group 1 foods (e.g. fresh produce, wheat, grains, nuts, and meat) are found in small proportions or even absent from, ultra-processed products [7]. UPFs are specially manufactured to target the taste preferences of the current generation, making them all the more appealing and

DOI: 10.54254/2753-8818/2025.AU23542

preferable. Although tasty, the processing methods that these foods go through have been shown to rid these foods of their natural micronutrient values; hence studies have shown that a modern diet high in UPF consumption is directly correlated with micronutrient deficiency risk. This article will explore the different categories of UPFs, and popular processing methods associated with each, and ultimately discuss the micronutritional compositions of these foods as a result of such processing methods. Different health risks associated with the modern diet of high consumption of UPFs and micronutrient deficiencies will also be further explored.

2.1. The rise of UPFs

The development of food preparation, cooking techniques, and methods for cultivating, preserving manufacturing, and processing food has played a crucial role in the evolution and adaption of humans in modern society, ultimately resulting in a global nutritional transition.

2.1.1. Globalization and industrial growth

The Industrial Revolution began roughly in the 1800s, notably in Europe and the US. Going into the 1930s, technology began to mature heavy industrial machinery began to enter the food industry aiming to profit off selling food adapted to taste profiles and increase shelf life by transforming the scale and nature of food supplies. Sugaring, salting, canning and bottling, chilling, and freezing were symbolic methods during the early stages of food processing, significantly increasing the appeal, appearance, and shelf-life of the food. Mass production was achieved through the development of machinery and farming mechanisms, resulting in increased food availability and accessibility. UPFs, although preliminary compared to modern times, came to trend during the 1980s. These food options aligned with the growing pace of life and appealed to consumers through their convenience and flavor. The growing convenience of transportation allowed Europe and the US to commercialize their products to foreign countries, catalyzing nutritional transitions across different cultures, often resulting in a loss of cultural food and an alignment of health risks worldwide. Mortality trends in Greece demonstrate their nutritional transition. The mortality by heart disease increased from 2% to 20.9%, by a factor of 10, from 1918 to 2020 [8,9]. Famous for the Mediterranean diet, which is known for its benefits for longevity and heart health, the traditional eating habits of its people have largely been abandoned due to globalization and urbanization.

2.1.2. Behavioral and economic changes

Behavior and economic changes in modern society are heavily intertwined and cannot be analyzed individually. Due to economic growth, population growth urbanization, and inflation, cities worldwide have seen exponential growth in rental prices [10]. Growths in rental and housing prices inevitably affect the behavioral patterns of the population, specifically their eating habits. Due to such reasons, studio apartments that come without kitchen areas have trended in recent years; combined with the increased pace of life leading to less time for food preparation, consumption of frozen and fast food has all the more become appealing to the young working population. However, in recent years, inflation and an increase in the minimum wage have spiked labor costs, resulting in a rise in dining/menu prices. Changing lifestyles and spiking prices, combined with a transition of gender roles and social values of modern society have led the way to busy schedules; dual-income households further contribute to the rising demand for time-effective and affordable meal options. Simultaneously, growth in food retailers, supercenters, and convenience stores continues to push the population to consume ready-made frozen meals, ultra-process with flavorings and additives, ultimately resulting in nutritional transitions from homemade meals to high consumption of ultra-processed meals and fast food. The rising prices and decreasing availability of organic whole foods have also made it

DOI: 10.54254/2753-8818/2025.AU23542

harder for households to consume healthy food daily. This phenomenon can be found especially prevalent in low-income groups where a higher percentage of household earnings must be spent on food purchases.

2.2. Nutritional composition and general health risks

UPF products are rarely the result of only one treatment, hence the name "ultra-processed". Figure 1 shows common processing methods used in the production of UPFs. Breakfast cereals, designed for children as a supposedly healthy, palatable, and time-effective breakfast option undergo various processing methods, including mechanical treatments such as refining flour and thermal processes like extrusion cooking which involve high pressure and temperatures to gelatinize starch. These cereals, specially adapted to appeal to children are often subjected to grinding and the incorporation of ingredients like salt, sugar, fats, and a variety of food additives for preservation, taste enhancement, and visual appeal. Past studies agree that regular consumption of sugar-sweetened cereal and obesity risks demonstrate a positive correlation due to the nutritional composition and processing methods that go into the production of cereal products which result from the calorie-dense characteristic of breakfast cereals. Past studies, including Thompson et al., Lee et al., and Smith et al. have concluded that breakfast cereals, especially ones marketed towards children, show undeniable correlations with obesity due to their high sugar and low fiber content. Studies based in Australia associated increased consumption of UPFs with higher non-recommended intake of free sugar, saturated fat, and sodium [11], and poorer dietary quality [12].

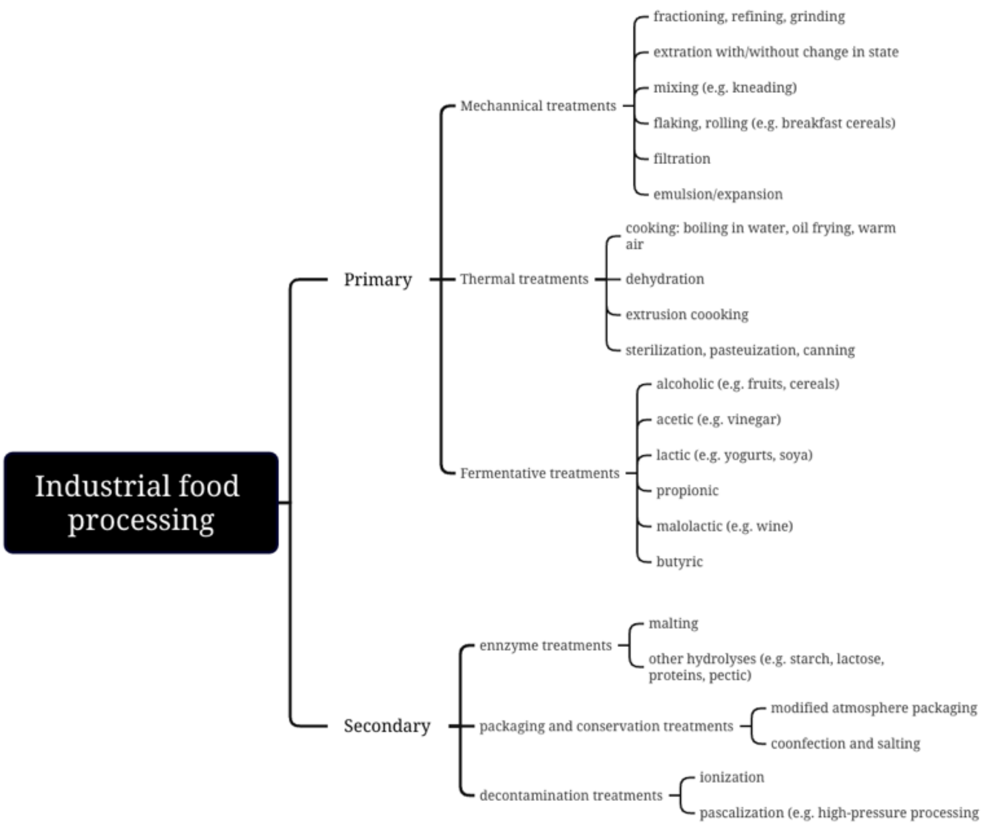

Figure 1: Common industrial processes [8]

DOI: 10.54254/2753-8818/2025.AU23542

Numerous studies, including the review [13] are in agreement that high consumption of UPF ultimately results in increased obesity, diabetes, hypertension, dyslipidemia, and low HDL cholesterol concentration.

Industrial food processes replenish raw ingredients of their natural nutritional value through processing methods like milling, peeling, excessive heating, refining, and physical grinding. Serving to enhance flavor, preservation, and improve texture and moisture retention, synthetic and non-synthetic additives found common in processed food include high-fructose corn syrup, hydrogenated oils, flavoring agents, and emulsifiers. Sold B to B in large bulk quantities and offered as cheaper, more convinient, and effective options compared to whole foods.

Food additives like sodium benzoate and potassium sorbate are commonly used in industrially manufactured food to extend shelf life and visual appearance. These additives primarily act as antimicrobial agents to prevent the growth of bacteria, mold, and yeast and are commonly found in acidic food and beverages like carbonated drinks, mayonnaise, and yogurts. While consumption in regulated servings may cause no observative effect, studies have shown that when accumulated consumption is followed with negative health implications; genotoxic and carcinogenic qualities result in increased cancer risk; liver and renal damage have also been observed from excessive intake of chronic consumption of food additives.

2.3. Impact on micronutrient intake

2.3.1. Relationship between high UPF diet and micronutrient deficiency

As aforementioned, diets high in UPFs are closely linked to numerous health risks, partially due to inadequate micronutrient consumption and poor dietary diversity. Research conducted in various countries including the US, UK, Canada, Brazil, Mexico, Chile, Columbia, Greece, and Australia agrees on the positive association between nutritional imbalances and UPF-rich diets. These studies [14] reveal that increased UPF consumption correlated with reduced intake of essential vitamins. Other micronutrients down in deficit include potassium, phosphorus, magnesium, calcium, zinc, and folate.

In a study based in Australia [15], data was collected on 9519 households and a total of 12153 Australians 2 years and older were interviewed between May 2011 and June 2012. 24-hour dietary recalls were used to collect information from individuals by trained interviewers using the Automated Multiple-Pass Method. The results collected were shown to be consistent with similar population-based studies based in Canada, Brazil, Mexico, and the US.

Due to the extensive processing that the ingredients of UPFs go through, micronutrients are stripped away for enhanced flavor, texture, and visual appearance. For example, regaining grains removes the bran and germ, components rich in B vitamins, iron, and magnesium [16]. To further enhance flavor, texture, and shelf life, the additives and preservatives added may displace nutrient-dense ingredients. Displacement of whole food in an individual's diet may also take place due to a dietary shift, resulting in a reduction in net intake of essential vitamins and minerals.

2.3.2. Comparing natural and synthetic micronutrients

Due to this reason, many manufacturers tend to add synthetic micronutrients into their products to increase their marketing advantage. These fortified micronutrients, however, are often insufficient to compensate for the overall micronutrient loss during processing. Nutrient synergy has also been found limited compared to whole foods, as these forms of added nutrients are often found in isolation, with a lack of interaction with other forms of nutrition. Vitamin C, for example, is typically accompanied by bioflavonoids, when found in natural sources, which enhance absorption and antioxidant effects exhibited in the human body [16].

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A randomized pilot trial [17] published in March 2020 comparing the bioavailability and effects of synthetic and natural vitamin B complexes concluded that natural B vitamins exhibited a stronger influence on metabolic parameters. Significant reductions in homocysteine levels and oxidative stress markers were also observed during the study, suggesting that natural B vitamins exhibited enhanced efficacy and bioavailability compared to synthetic ones.

Although differences in bioavailability exist between natural and synthetic forms of micronutrients, these differences also vary depending on form and formulation. UPFs in the form of supplements, found in tablets or commercial food items, specialize in correcting specific deficiencies. A balanced and healthy diet would, hence, prioritize whole foods while using supplements to address specific dietary gaps.

3. Health implications of micronutrient deficiencies

The rising prevalence of chronic micronutrient deficiencies, often exacerbated by diets high in UPFs, poses significant health risks to the modern population. By highlighting their role in metabolic dysfunction, immune impairment, and long-term disease development, this section explores the physiological and clinical consequences of these nutritional gaps.

3.1. Common micronutrient shortfall in UPF diets

While the nutritional profiles of UPFs lack essential micronutrients due to the complex industrial processing methods and displacement of whole foods, they have still managed to dominate modern diets. As mentioned in section 2.1, these foods are high in refined sugars, saturated and trans fats, and synthetic additives to enhance flavor, and appearance and improve shelf life. Their lack of micronutrients, specifically crucial vitamins and minerals, is mainly due to the displacement of whole foods during production processes. Studies based in Australia, Canada, UK, Brazil, Chile, Mexico, Columbia, and the US have collectively agreed that UPF-rich diets are nutritionally unbalanced; these studies have reported an inverse correlation between the rise of UPF-dominated diets with an intake of micronutrients like vitamins A, C, D, E, B12, B6, and β-carotene, potassium, riboflavin, niacin, folate, zinc, calcium, phosphorus, magnesium, thiamine, and iron [14].

A cross-sectional study [18] performed in Brazil from 2008-2009 further supported these studies; the content of 10 micronutrients (vitamin B12, C, D, E, niacin, pyridoxine, copper, magnesium, manganese, and zinc) commonly found in natural or minimally processed food was more than double the amount present in UPFs. However, this study showed a positive association between UPFs and calcium consumption. This is explained by the prevalence of calcium in many semi-ready-to-eat meals, fast food (often rich in cheese), and dairy drinks with added sugar.

The nutritional unbalances present in UPFs can be partially explained by the complex processing production methods that they undergo. Magnesium and zinc, crucial for metabolic and immune function, are frequently found insufficient due to the lack of nuts, seeds, and legumes. The presence of non-heme iron while displacing iron-rich whole foods like red meat and leafy greats further explains the lack of iron found in UPFs [19].

Fiber and phytonutrients, used to enhance micronutrient absorption, are stripped away during processing, furthering the prevalence of such deficiencies. Without dietary diversification, reliance on UPF-high diets may inevitably result in clinical and subclinical health implications that increase the risk of long-term chronic diseases.

DOI: 10.54254/2753-8818/2025.AU23542

3.2. Clinical and subclinical health effects

As aforementioned, micronutrients play critical roles in the maintenance of bodily functions. Although deficiencies in micronutrients do not always manifest themselves clinically, subclinical deficiencies can be harmful to long-term health.

Dietary diversity, associated with a balanced nutritional intake has been proven to link to Non-communicable Diseases (NCDs) prevention. This was demonstrated in studies amongst adult men in India, community-dwelling elderlies in Thailand, and primary schoolchildren in Côte d'Ivoire, where the prevalence of NCDs showed a strong positive association with low dietary diversity[14].

Micronutrient deficiencies pose the greatest threat to pregnant women and children under the age of 5 [20]. Such an incidence of malnutrition has been demonstrated by a study focused on maternal and child undernutrition. It was shown that the nutritional status of women before and during pregnancy greatly impacts the pregnancy outcome for both the mother and the baby. These deficiencies in pregnancy directly influence the fatal survival rate and rate of miscarriage, organ formation, duration of gestation, rate of fatal growth, and low birth weight. Long-term consequences of such deficiencies may even go on to follow the child into adulthood; these include the decreased infant mortality rate, body composition, cardiometabolic risk, immunity, respiratory function, and cognition. Recent studies have also shown the link between childhood undernutrition and NCDs, suggesting that early-life deficiencies in micronutrients, followed by rapid weight gain later in childhood through nutritionally unbalanced diets may influence long-term cardiovascular and metabolic health. Poorer cognitive development, educational outcomes, and even behavioral problems have been shown to spiral from micronutrient deficiencies during the early stages of life [21].

Overt conditions like iron-deficiency anemia, scurvy, or ricks manifest from clinical deficiencies which have become increasingly prevalent in low- and middle-income countries where UPFs displace traditional nutrient-dense diets. Subclinical deficiencies, though less visible, nonetheless contribute to long-term chronic diseases by impairing metabolic functions, immune response, and cognitive performance [21] Common in high UPF diets, inadequate zinc intake, for example, greatly compromises immune function, increasing individuals' susceptibility to infections. Similarly, insufficient intake of B vitamins, a result of diets high in refined-grain-based UPFs, elevates homocysteine levels and increases cardiovascular risk [22]. Although it has been commonly believed that high sugar diets and body fat are the main setters of prediabetes and type 2 diabetes, studies have also demonstrated that magnesium deficiencies linked to insulin resistance and hypertension also contribute to the cause.

4. Solutions and policies

Efforts to combat hidden hunger began in the 1990s with the first International Conference on Nutrition (ICN) in 1992. National Plans of Action were established to reduce micronutrient deficiencies and diet-related diseases. When progress was hindered by poor implementation, the 2000 Millennium Development Goals (MDGs) furthered the combat by targeting poverty, hunger, and child mortality. The second ICN, in 2014, reapproached global malnutrition by emphasizing policy coherence across sectors. In 2015, the MDGs were replaced by the Sustainable Development Goals (SDGs), focusing on ending hunger across nations and improving nutritional balance. In efforts to reinforce global commitments, the years 2016-2025 were declared by the UN the Decade of Action on Nutrition. This highlights the global need for efficiency, efficacy, and policy implementation from governments, as despite these frameworks, challenges have persisted due to inadequate funding and coordination.

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As of 2023, few policies directly target the consumption of UPFs but promote, instead, the consumption of healthy diets. The 2025-2030 Advisory Committee has been tasked to evaluate research related to UPF food consumption as the UPF category has not yet been added to the US Dietary Guidelines for Americans.

Interventions proposed by The Journal of Pediatrics [23] included nutritional education, fortification, and supplementation. Financial assistance programs like HealthWell have taken these burdens into their own hands by sourcing eligible patients in the US with vitamins and supplements to manage Alagille Syndrome. Although supplements are a common way to mitigate the deficiency of single micronutrients, supplement use has also increased the probability of excessive intake of certain nutrients [23]. Moreover, children who are most at risk for micronutrient deficiencies have shown to be less likely to be on supplements, specifically, minority children (non-Hispanic black and non-black Hispanic) living in the US [23], highlighting the need for a balanced, healthy diet.

With this alarming trend of micronutrient malnutrition and UPF consumption, studies have proposed plausible economic policies. An agent-based model simulated a model with 1000 individual agents with similar income, educational attainment, and UPF purchasing speculation with the average adult women in Mexico was created in a study. Relative to the baseline, a 20% tax would decrease purchasing by 24%, similar to the magnitude of the effect of a nutrition warning label policy [24]. A 50% advertising increase or decrease had a comparatively smaller effect on consumer demands [24]. However, this study also notes that due to the existing social patterns in UPF purchasing, such implementations are likely to increase societal inequality.

5. Conclusion

Through an in-depth analysis, this article demonstrates the evident correlation between UPF consumption and micronutrient deficiency risk in the modern diet. Despite their convenience and palatability, the industrial processing they undergo strips them away of essential vitamins and minerals while adding excessive sugars, fats, and additives, making them nutrient-poor and calorie-dense dietary options. The displacement of minimally processed foods to enhance flavor, texture, and shelf-life results in nutritional imbalances, leaving populations vulnerable to deficiencies in iron, zinc, vitamin A, and other micronutrients that play critical roles in metabolic, immune, and cognitive functions. Epidemiological evidence, pointing out the correlation between high UPF intake and increased risk of obesity, cardiovascular diseases, and diabetes, highlights the dual burden of micronutrient deficiency and excessive consumption of "empty calories".

Of the population, children, pregnant women, and low-income groups are at the greatest risk for the heightened health implications caused by micronutrition deficiencies. These include increased risk for developmental impairment, pregnancy complications, and chronic diseases. Subclinical deficiencies further compound long-term health burdens, weakening immunity and elevating oxidative stress. While fortification of food and supplementation offer partial, short-term solutions, they are unable to fully replicate the synergistic benefits of the natural nutrients that come from whole foods; this underscores the need for dietary diversification.

To combat hidden hindrances in modern society, policymakers must organize and implement multifaceted strategies that aim to reduce UPF accessibility through methods like taxation and marketing restrictions, while simultaneously promoting affordable, nutrient-dense whole-food alternatives. Educational programs should be emphasized to inform and empower individuals to make responsible dietary choices. All in all, global efforts must tackle perpetuating reliance on UPFs due to socioeconomic inequality and individuals with the right to make healthier choices. This silent epidemic of hidden hunger can only be mitigated through concerted actions from societies, ultimately achieving the SDG's nutritional targets of curbing UPF reliance and dominance in food systems.

DOI: 10.54254/2753-8818/2025.AU23542

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