

REVIEW ARTICLE

Ultra-Processed Foods

Future perspectives: Current trends and controversies of meat alternatives classified as ultra-processed foods

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National Research Foundation of Korea (NRF); Korea government (MSIT), Grant/Award Number: (RS-2023-00211920); development fund foundation, Gyeongsang National University, 2024

Abstract

This study reviewed the current state of meat alternatives including plant-based or cell-based ingredients and discussed the contentious factor surrounding the classification of meat alternatives as ultra-processed foods (UPFs). The term UPFs refers to foods undergoing extensive industrial processing and containing additives such as flavors, colors, emulsifiers, and preservatives. There is growing concern regarding the potential adverse effects of UPF consumption on health, nutrition, and sociodemographic factors. Additionally, this study examined the market potential, drivers, and barriers associated with different types of meat alternatives. In light of barriers focused on UPFs, meat alternatives can be disputed in that they undergo extensive processing and are highly processed, including numerous ingredients, while meat alternatives offer potential solutions to the environmental, ethical, and health issues associated with animal meat consumption. Consequently, it is important to distinguish them from other UPFs, which are known to have detrimental effects on health. Therefore, this paper proposed a reassessment of the UPF classification system, the establishment of uniform nutritional profiles for meat alternatives, and the dissemination of their beneficial impacts. These measures are necessary to validate the exclusion of meat alternatives from the UPF category and to promote their development and adoption.

KEYWORDS

cell-based, meat alternatives, plant-based, ultra-processed foods

1 | INTRODUCTION

The global meat alternative industry is projected to reach a value of \$8.1 billion by 2026 (Realini et al., 2023). The most prevalent meat alternatives currently available include plant-based, cell-based, and insect-based alternatives, and mycoprotein (Lee et al., 2024a; Lee et al., 2023b). Meat alternatives are designed to replicate the taste, texture, and

nutritional characteristics of meat sourced from animals, primarily utilizing plant-based or cell-based ingredients. In recent years, meat alternatives have gained popularity, as consumers increasingly seek sustainable, ethical, and healthy options to meet their protein intake. However, concerns have been raised regarding the potential adverse effects of meat alternatives on human health and nutrition. Specifically, many of these products have been

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criticized for being ultra-processed foods (UPFs), containing numerous ingredients, and undergoing extensive processing (McClements, 2023). Certain meat alternatives, often referred to as UPFs, have sparked debates regarding several challenges and uncertainties, including their environmental impact, safety, regulation, and consumer acceptance. Despite the numerous opinions on the matter, the development of the alternative meat industry is necessary due to the benefits of environmental sustainability, improved animal welfare by eliminating unethical practices, reduced risk of disease transmission and antibiotic resistance, improved food security and nutrition, and significant growth potential in industries related to new food technologies. This review contributes to a better understanding of the current state of meat alternatives and the impacts associated with the consumption of UPFs from various perspectives. It also seeks to propose future perspectives on the controversy surrounding meat alternatives classified as UPFs in order to the development of the meat alternatives industry.

2 | FOOD CLASSIFICATION SYSTEM

The NOVA food classification system stands out as one of the most representative frameworks, categorizing foods into four types based on the extent and purpose of their processing (Monteiro et al., 2019). These categories are outlined as follows: (1) Unprocessed or minimally processed foods: Foods included within this category are considered natural and have undergone minimal processing. They generally contain only one ingredient. Examples include fresh fruits and vegetables, nuts, seeds, eggs, and milk. (2) Processed culinary ingredients: These substances are derived from unprocessed or minimally processed foods and are used to cook or season dishes. Examples include oils, fats, sugars, salt, and spices. (3) Processed foods: This category includes foods that have undergone some processing, often to enhance their flavor, texture, or shelf life. However, they typically retain much of their original nutritional value. Examples include canned vegetables, cheese, bread, and cured meats. (4) UPFs: These are foods that have undergone extensive industrial processing and contain additives such as flavors, colors, emulsifiers, and preservatives. UPFs typically contain minimal or no whole foods and are often high in unhealthy fats, sugars, and salt. Examples include packaged snacks, sugary drinks, ready-to-eat meals, and fast food. Several food classification systems used in various countries are based on different criteria, including nutritional content, the degree of processing, or cultural significance. In Europe, the International Agency for Research on Cancer (IARC) and the European Prospective Investigation into Cancer and Nutrition (EPIC), as IARC-EPIC, provide valuable insights

into the complex relationships between diet, lifestyle, and health outcomes. Their research supports strategies and interventions aimed at reducing the incidence of diseases (Carretero et al., 2020). In the United States, the International Food Information Council system categorizes foods into four groups based on their nutritional characteristics and recommended consumption frequency. Additionally, the University of North Carolina system categorizes foods based on their nutrient density and overall healthfulness to guide consumers toward making healthier food choices by providing a simple color-coded system (Petrus et al., 2021). In addition to these systems, the International Food Policy Research Institute in Guatemala, SIGA in France, and NIPH in Mexico have also classified foods (Petrus et al., 2021; Sadler et al., 2021). Although the NOVA system is the most widely recognized in categorizing foods, it is also regarded as confusing and controversial in its overall acceptance. This is mainly due to its simplistic nature and failure to adequately evaluate the nutritional attributes of meat alternatives based on plant-based or cell-based sources.

3 | CONSUMPTION OF UPFS AND POTENTIAL ADVERSE EFFECTS

It has been observed that the categorization of plant-based meat alternatives as UPFs in the NOVA food classification system is impeding the growth of the alternative protein industry. A recent survey conducted by the European Institute of Innovation and Technology revealed that 65% of Europeans express concern regarding the potential negative health effects of UPFs. Furthermore, among this group, 54% tend to avoid consuming UPFs, including plant-based alternative proteins. As mentioned previously (Section 2) in the food classification system, UPFs undergo extensive processing and often contain various additives, and are typically classified as foods detrimental to health. Numerous studies have established correlations between the consumption of UPFs and adverse effects on health, nutrition, and sociodemographic factors, predominantly yielding negative outcomes (Table 1).

In this context, the first issue to address is the relationship between the consumption of UPFs and various health risks, including hypertension, mortality, cancer, inflammatory bowel disease (IBD), obesity, cardiometabolic diseases, and type 2 diabetes (Barbosa et al., 2022; Cordova et al., 2021; Delpino et al., 2022; Dicken & Batterham, 2021; Rico-Campà et al., 2019). High consumption of UPFs has been reported to alter the dietary patterns of populations, particularly contributing to the development of arterial hypertension, particularly among adults and older individuals (Barbosa et al., 2022). However, the evidence for an association between geographical factors

TABLE 1 Summary of adverse effects associated with the consumption of ultra-processed foods.

Major issue	Factor	Result	Implication	Reference
Health risk	Arterial hypertension	UPFs are characterized by high energy density and an abundance of salt, sugar, and fat, posing significant health risks.	Urgent government intervention is required to reduce UPF consumption and promote healthy eating habits.	(Barbosa et al., 2022)
Health risk	Inflammatory bowel disease	Increased consumption of UPFs was associated with a higher risk of developing inflammatory bowel disease (including Crohn's disease or ulcerative colitis).		(Narula et al., 2021)
Health risk	Colorectal cancer across the United States	In men, the group with the highest consumption of UPFs had a 29% higher risk of colorectal cancer, with a 72% higher risk of colon cancer. In men, an increased risk of colorectal cancer was observed with higher consumption of processed meats/poultry/seafood-based fast foods and sugar-sweetened beverages. In women, no significant association was observed between overall UPF consumption and the risk of colorectal cancer. In women, an increased risk of colorectal cancer was noted with higher consumption of ready-to-eat/heated mixed dishes.	The importance of public health in improving population health outcomes by limiting the consumption of specific types of UPFs has been highlighted.	(Wang et al., 2022)
Health risk	Cancer and cardiometabolic diseases across seven European countries	Higher consumption of UPFs was associated with an increased risk of cancer and cardiovascular diseases.	Reducing the consumption of specific UPFs and replacing them with minimally processed food is necessary.	(Cordova et al., 2023)
Health risk	Obesity across nine European countries	Higher consumption of UPFs is associated with an increased risk of weight gain and obesity.	A public health campaign promoting the replacement of UPFs with minimally processed foods can help prevent obesity.	(Cordova et al., 2021)
Health risk	Obesity in the UK adults	The highest consumption of UPFs posed a significantly increased risk of overall obesity and abdominal obesity compared to the lowest consumption group.	Policies promoting the consumption of fresh or minimally processed foods and reducing the intake of UPFs should be considered.	(Rauben et al., 2021)
Health risk	Obesity and health-related outcomes	Consumption of UPFs is associated with the development of chronic diseases such as obesity, cardiovascular diseases, cancer, and type 2 diabetes. A diet high in UPFs is inversely associated with the consumption of fruits, vegetables, legumes, and seafood, leading to negative health effects.	There is debate regarding whether the harmful effects of UPFs stem from their lack of nutrients or from the processing itself.	(Dicken & Batterham, 2021)
Health risk	Obesity and cardiometabolic risk	Consumption of UPFs is associated with an increased risk of general and abdominal obesity. UPFs are also associated with an increased risk of developing cardiovascular risk factors such as hypertension, diabetes, and dyslipidemia.		(Mambrini et al., 2023)
Health risk	Type 2 diabetes	A meta-analysis of 18 studies involving a total of 1.1 million individuals was conducted. In 72% of these studies, an association between the consumption of UPFs and the risk of diabetes was confirmed.		(Delpino et al., 2022)

(Continues)

TABLE 1 (Continued)

Major issue	Factor	Result	Implication	Reference
Health risk	Type 2 diabetes	Over a period of 5.4 years, the group with high consumption of UPFs had a 44% higher risk of developing type 2 diabetes compared to the low consumption group.	Urgent public health measures are needed in the United Kingdom and globally to reduce UPF consumption.	(Levy et al., 2021)
Health risk	Excess weight in the United States	High consumption of UPFs is associated with higher BMI and waist circumference and an increased risk of overweight and abdominal obesity. Gender differences: In women, there was a significant increase in the association between UPF consumption and weight.		(Juul et al., 2018)
Health risk	Excess weight and co-morbidity risk	The consumption of UPFs is consistently associated with an increased risk of weight gain and obesity-related coexisting diseases in both adults and children. UPFs have a high energy density and low nutritional density, which is associated with an increased risk of obesity and coexisting diseases.	Policy efforts to reduce UPF consumption are necessary, as they are effective in promoting healthy eating habits and reducing the risk of chronic diseases.	(Crimarco et al., 2021)
Health risk	All-cause mortality	The consumption of UPFs was associated with a relative increase in overall mortality risk by 62%. An additional daily serving of UPFs increased mortality risk by 18%.		(Rico-Campà et al., 2019)
Health risk	Cardiovascular mortality	The highest consumption of UPFs increased risks of cardiovascular disease mortality, ischemic heart disease/stroke mortality, and all-cause mortality. The association between biomarkers of kidney function and the risk of mortality from all causes by UPFs was 20.1%.	A national nutrition policy advocating for limiting UPF consumption and the promoting natural or minimally processed foods is necessary.	(Bonaccio et al., 2021)
Health risk	Mortality	High consumption of UPFs is associated with increased mortality. Overall consumption of animal-derived foods (meat, dairy, eggs) was not associated with mortality rates; however, red meat consumption was associated with mortality rates.		(Orlich et al., 2022)
Nutritional concept	Sodium intake	Food and beverage processing levels were categorized, and sodium content was evaluated in Australian long-day care centers. Sodium contribution: UPF accounted for 40% of the total sodium intake.	It is recommended to replace UPFs with low-sodium alternatives.	(O'Halloran et al., 2018)
Nutritional concept	Dietary nutrient profile related chronic noncommunicable diseases in the United Kingdom	The increased consumption of UPFs is associated with an increase in the intake of carbohydrates, added sugars, total fat, saturated fat, and sodium, combined with a decrease in the intake of protein, fiber, and potassium. High consumption of UPFs is associated with an increased risk of various noncommunicable diseases.	Reducing the consumption of UPFs and replacing them with unprocessed or minimally processed foods contributes to improving nutritional profiles and preventing noncommunicable diseases.	(Rauber et al., 2018)
Nutritional concept	Fatty acids in Tunisian children	Increased consumption of UPFs among Tunisian children was associated with exceeding recommended levels of saturated fatty acids (SFA).	Strategies are needed to reduce the intake of UPFs and increase the consumption of nutritionally rich foods.	(Dogui et al., 2022)

(Continues)

TABLE 1 (Continued)

Major issue	Factor	Result	Implication	Reference
Nutritional concept	Worse nutrient profile in the New Zealand supermarkets	Ultra-processed food dominance: 83%–84% of packaged foods in New Zealand supermarkets were UPFs. Nutrient profile score (NPSC) indicates the worst nutrient profile (NPSC = 11.63).	There is a need for supermarket interventions to reduce the number of UPFs and improve the nutritional profile of products.	(Luiten et al., 2016)
Nutritional concept	Dietary protein density and energy intake in the United States	UPF consumption was associated with higher total energy intake. UPF consumption was inversely associated with dietary protein density.	Reducing UPF consumption could be an effective strategy to increase dietary protein density and prevent excessive energy intake.	(Martínez Steele et al., 2018)
Nutritional concept	Dietary diversity and micronutrient intake in the Australian population	Negative correlation was found between UPFs and dietary diversity. Increased consumption of UPFs was linked to lower intake of vitamins (A, E, C, B9, and B12) and minerals (zinc, calcium, iron, magnesium, potassium, and phosphorus). UPF consumption resulted in poor nutritional balance.	Enhancing dietary habits and reducing UPFs can improve diet quality in Australia.	(Houshialsadat et al., 2024)
Nutritional concept	Nutrition and public health and environmental sustainability	UPF consumption is associated with adverse health and environmental outcomes.	There is a necessity for systematic research to examine the holistic impact of UPF production, distribution, consumption, and waste on sustainability metrics.	(Lawrence, 2023)
Correlation with sociodemographics	Diet of adults in the French population	Cohort study of NutriNet-Santé in France. UPFs make up 18.4% by weight and 35.9% of total energy intake in the French adult diet. Consumption of UPFs was associated with demographic factors such as male gender, younger age, lower education level, smoking, and being overweight or obese. Consumption of UPF was associated with dietary patterns characterized by lower fruit and vegetable intake, higher consumption of sweet products and soft drinks, and higher energy and sugar intake. High UPF intake correlates with a nutritionally unbalanced diet.	The findings could inform policy interventions aimed at reducing UPF consumption, such as food labeling, taxes on UPF, and promoting whole and minimally processed foods.	(Julia et al., 2018)
Correlation with sociodemographics	Socio-demographics and time scarcity	High time scarcity is linked to the consumption of UPFs among parents in Norway. Sociodemographic factors, including gender, ethnicity, education level, and number of children, influenced choice of UPFs.	Longitudinal studies are needed to gain a better understanding of the relationship between these factors.	(Djupegot et al., 2017)
Correlation with sociodemographics and health risk	Socio-demographics in Australian adults	Individuals aged 19–30 and those with lower education levels tend to consume more UPFs. Consumption of UPFs is associated with greater area-level disadvantage and households with lower income levels. UPF consumption is linked to poorer diet quality and an increase in discretionary foods, saturated fat, and added sugar.	Reducing UPF consumption improves diet quality and dietary habits.	(Marchese et al., 2022)

Abbreviation: UPFs, ultra-processed foods.

(such as Asian or African communities) and UPF consumption is lacking and warrants further study. It is essential to emphasize the importance of addressing UPF consumption through public health interventions and policies to reduce the risk of arterial hypertension and improve population health. Additionally, UPFs may also influence the risk of developing IBD, including Crohn's disease and ulcerative colitis. Preclinical and clinical evidence suggests that non-nutritive ingredients and additives in UPFs can have detrimental effects on components of the intestinal barrier, leading to aberrant immune responses (Narula et al., 2021; Vissers et al., 2022). Wang et al. (2022) found significant differences in the risk of colorectal cancer based on categories of UPF consumption between men and women. Men who were in the highest quantile of UPF consumption exhibited a 29% higher risk of developing colorectal cancer, with a particularly strong association observed for distal colon cancer, which showed a 72% increased risk. In contrast, women did not exhibit a significant association between UPF consumption and the risk of colorectal cancer. The disparity may be attributed to differences in dietary habits: men primarily consumed meat/pork/seafood-based ready-to-eat products and sugar-sweetened beverages, whereas women consumed ready-to-eat/heated mixed dishes. This suggests that the impact of UPFs on the risk of colorectal cancer may vary depending on the type of UPFs consumed. High consumption of UPFs is associated with an elevated risk of chronic diseases, including obesity, hypertension, diabetes, and dyslipidemia (Cordova et al., 2021; Dicken & Batterham, 2021; Mambrini et al., 2023). Cordova et al. (2021) reported that individuals in the highest quintile of UPF consumption had a 15% higher risk of becoming overweight or obese compared to those in the lowest quintile, based on a comprehensive prospective study conducted across nine European countries. Furthermore, Mambrini et al. (2023) reviewed the positive association between UPFs and the incidence of cardiometabolic risk through prospective studies, reinforcing the global relevance of these findings. Participants in the highest quantile of UPF consumption had a 62% higher hazard for all-cause mortality. Additionally, each additional serving of UPFs increased all-cause mortality by 18% (Rico-Campà et al., 2019). Among UPFs, the consumption of animal-derived food (e.g., meat, dairy, eggs) did not show an association with mortality rates, although red meat consumption was specifically linked to higher mortality rates (Orlich et al., 2022).

Second, UPFs are often deficient in essential nutrients and high in saturated fats, sugar, and salt, thereby contributing to nutritional issues. In Australian long-day care centers, snack foods classified as UPFs were the major contributors to total daily sodium intake, accounting for 40% (O'Halloran et al., 2018). Furthermore, high intake

of carbohydrates, added sugars, and saturated fat, combined with a decrease in the intake of healthy nutrients such as protein, fiber, and potassium, is associated with an increased risk of various noncommunicable diseases (Rauber et al., 2018). Several countries have expressed concern regarding the negative impact of unhealthy and unsustainable diets resulting from high UPF consumption. Consequently, there is growing support for policy actions such as labeling, taxes, and marketing restrictions aimed at reducing UPFs intake (Houshialsadat et al., 2024; Lawrence, 2023; Martínez Steele et al., 2018).

Third, sociodemographic aspects influence the consumption of UPFs. Factors such as gender, ethnicity, education level, daily habits, time scarcity, and number of children have been found to contribute to increased UPF consumption (Djupegot et al., 2017; Julia et al., 2018). Another study found that individuals aged 19–30 or those with low education and income levels tend to exhibit higher UPF consumption (Marchese et al., 2022). As mentioned previously (Section 3), numerous studies have demonstrated correlations between UPF consumption and adverse health effects. These studies suggest the need for urgent government intervention, public health campaigns, and policies promoting the consumption of fresh or minimally processed foods to improve nutritional profiles and prevent various diseases.

However, it is important to note that the studies examined commonly known confectionery items such as sweet, fatty, or salty snacks, biscuits, instant products, prepared dishes, and animal-based products. Otherwise, Cordova et al. (2023) found that consumption of ultra-processed breads and cereals was inversely associated with the risk of multimorbidity (HR per 1 SD 0.97; 95% CI: 0.94–1.00), though the confidence interval suggests some uncertainty. No association with the risk of multimorbidity was found for other groups, including sweets and desserts, savory snacks, plant-based alternatives, ready-to-eat or heat-mixed dishes, and other unspecified UPFs (Cordova et al., 2023). Notably, none of these studies specifically examined the consumption of plant-based meat alternatives. Thus, meat alternatives, currently classified under the NOVA food classification system as part of UPFs, may face negative perceptions, potentially hindering their growth.

4 | PLANT-BASED AND CELL-BASED MEAT ALTERNATIVES

Meat alternatives, also referred to as meat substitutes or meat analogs, are products that aim to replicate the taste, texture, and appearance of traditional meat products using non-meat ingredients. These alternatives can be classified into two main categories: plant-based meat

alternatives and cell-based meat alternatives. Plant-based meat alternatives utilize plant proteins, such as soy, pea, wheat, legumes, or other protein-rich plant ingredients, to achieve meat-like textures and flavors (Lee et al., 2023b). Plant-based meat alternatives often employ refined and processed ingredients, such as textured vegetable protein, protein isolates, or concentrates, and are used to create meat and dairy alternatives, including milk, burger patties, sausages, chicken substitutes (nuggets or fillets), meatballs, and other meat products (Lee, Lee, Jeong, Kim, Yun, Mariano, et al., 2023b). Prominent companies producing plant-based meat alternatives include Impossible Foods, Beyond Food, Quron, MorningStar Farms (Kellogg's), Lightlife, Gardein (Conagra Brands), Tofurky, Nestlé, Field Roast (Maple Leaf Foods), and JUST Food, and their products are labeled as plant-based alternative meat products (Lee et al., 2023b). Cell-based meat alternatives, also known as cultured meat, lab-grown meat, or clean meat, are products that utilize animal cells, including muscle, fat, and connective tissue, to grow meat-like tissues using various technologies such as scaffolds, bioreactors, or 3D bioprinting (Jeon et al., 2024; Lee et al., 2023a; Lee et al., 2024b). The main companies conducting research and development in cell-based meat alternatives include Mosa Meat, Memphis Meats, JUST, Aleph Farms, Future Meat Technologies, Blue Nalu, Higher Steaks, Novameat, and Gourmey.

5 | CURRENT STATE OF MEAT ALTERNATIVES

The global market for meat alternatives is anticipated to undergo rapid growth in the coming years, driven by the rising demand for alternative protein sources. According to a report by Markets and Markets, the global market for plant-based meat alternatives was valued at \$7.9 billion in 2022 and is projected to reach \$15.7.3 billion by 2027, with a compound annual growth rate (CAGR) of 14.7% from 2022 to 2027 (Markets and Markets, 2022). The report also predicts that the global market for cell-based meat alternatives will be valued at \$198.99 million by 2023 and is expected to grow at a CAGR of 12.90% to reach \$465.38 million by 2030 (Research & Markets, 2024).

The primary drivers for the growth of meat alternatives include the rising concerns regarding the environmental, ethical, and health impacts associated with the consumption of animal meat (Table 2). Livestock-derived meat is linked to high greenhouse gas emissions, land and water use, deforestation, biodiversity loss, and animal welfare issues (Grossi et al., 2019; Xu et al., 2021). Furthermore, meat consumption has also been linked to an increased risk of chronic diseases such as cardiovascular disease, diabetes, obesity, and certain types of cancer (Giromini

& Givens, 2022; Richi et al., 2015; Wang & Beydoun, 2009). Meat alternatives present a potential solution to the aforementioned issues, as they can reduce the environmental footprint, animal welfare concerns, and health risks associated with meat production and consumption while providing comparable or superior sensory and nutritional characteristics (Flint et al., 2023; Nezelek & Forestell, 2022). Although plant-based and cell-based meat alternatives are gaining popularity for various reasons, such as health benefits, environmental sustainability, animal welfare, and cultural or dietary preferences, several challenges remain. These include high costs, safety concerns, consumer preferences, and consumption behavior. Compared to traditional meat, meat alternatives remain more expensive due to the high cost of ingredients, processing, and scaling. Additionally, these products are not widely available in the market, being mostly concentrated in developed countries with limited distribution channels. Regulatory challenges also pose a barrier. Meat alternatives are subject to different regulatory frameworks depending on the country, with products still awaiting approval or clarification. Furthermore, meat alternatives must overcome consumer perceptions of being unnatural, unhealthy, or unappealing, and address the ethical, religious, and social implications of replacing animal meat with alternative sources. Consequently, advancements in food technology and strategies to improve consumer perception are necessary to provide consumers with increasingly realistic and satisfying alternatives.

6 | CONTROVERSY SURROUNDING UPFS AND MEAT ALTERNATIVES

The replication of taste, texture, and overall sensory experience of plant-based alternative proteins relies on the use of various additives and processes. However, the incorporation of these additives and processes categorizes plant-based alternative proteins as UPFs. This classification not only applies to plant-based alternative proteins but also raises the possibility that cultured meat and all meat alternatives utilizing alternative proteins may also be classified as UPFs in the future. The classification of plant-based meat alternatives as UPFs has undeniably contributed to the negative perception of UPFs among most consumers, presenting a significant obstacle to the advancement of the alternative protein food market. Despite numerous studies indicating the potential of alternative protein foods to address future food and climate crises, as well as promote health benefits, the association with UPFs may hinder the growth of the alternative protein industry. Some studies argue that the classification of meat alternatives as UPFs fails to adequately reflect their unique characteristics.

TABLE 2 Summary of procs and cons of plant-based and cell-based meat alternatives.

Meat alternative type	Advantages	Disadvantages
Plant-based	More widely available and affordable Lower greenhouse gas emissions and water use than traditional meat Higher in fiber and lower in cholesterol and saturated fat than traditional meat Low animal welfare issues	Highly processed and may contain additives, preservatives, and artificial flavors. May lack certain essential amino acids, vitamins, and minerals that are present in animal meat. May have different sensory and functional characteristics than animal meat. May cause allergic reactions or intolerance in some consumers.
Cell-based	More identical to traditional meat in terms of sensory and functional characteristics No risk of zoonotic diseases, antibiotics, or hormones animal-derived meat Low animal slaughter or animal welfare issues	More expensive and less accessible than plant-based meat alternatives Higher energy and resource use than plant-based meat alternatives Unclear environmental impact and life cycle assessment Unclear safety, regulation, and labeling standards Low consumer acceptance and trust

One study asserts that soy-based meat and dairy alternatives, despite being classified as UPFs, offer high-quality nutrition that is comparable to unprocessed animal products. Therefore, they should not be disregarded solely based on their processing level (Messina et al., 2022). Ohlrau et al. (2022) investigated the consumption of UPFs and plant-based meat alternatives in Germany, focusing on their association with various dietary patterns and sustainability. Plant-based meat alternatives were consumed by a small fraction of participants (12.3%), predominantly within vegetarian diets, whereas UPFs such as convenience products, fast foods, sweet and salty snacks, and ultra-processed beverages were consumed by meat-eaters (Ohlrau et al., 2022). Furthermore, higher levels of education were found to be associated with increased consumption of plant-based meat alternatives, which contradicts the findings of Marchese et al. (2022) that suggested individuals with lower education levels tend to consume more UPFs. In terms of health implications, de las Heras-Delgado et al. (2023) evaluated the plant-based alternative products available in the Spanish market in comparison to animal products, focusing on their nutritional composition, profile, and degree of processing (de las Heras-Delgado et al., 2023). Most plant-based alternative products exhibit a superior nutrient profile compared to their animal-based counterparts. However, in the case of cheese, fish, and meat alternatives, plant-based options tend to have a poorer nutrient profile and undergo more processing (de las Heras-Delgado et al., 2023). One study has indicated that processed meat alternatives are high in protein content and may offer a healthier nutritional profile in terms of saturated fats compared to traditional meat products (Gastaldello et al., 2022). Furthermore, processed meat alternatives can be included as part of a healthy diet, especially for individuals seeking to reduce

their meat consumption without compromising on protein intake (Gastaldello et al., 2022). Plant-based meat alternatives can be redesigned to improve their nutritional profiles and health benefits, potentially offering comparable or even superior nutritional value compared to animal-based products (McClements, 2023). Additionally, another study suggests the possibility of controlling the composition, structure, and digestibility of plant-based meat alternatives to create healthier alternatives (McClements, 2023). Lee et al. (2020) also asserted that meat alternatives, such as plant-based meat alternatives, are considered good protein sources and can potentially replace traditional meat from a nutritional standpoint. Moreover, the authors suggest that meat alternatives are likely to play a diverse and potentially significant role in the future meat market, addressing both sustainability concerns and consumer dietary needs. In conclusion, the authors argued that plant-based foods should not be equated with other UPFs, such as snacks, as they do not pose the same health concerns. Plant-based foods provide high-quality nutrition and are comparable to their animal-based counterparts, which are classified as unprocessed or minimally processed (Messina et al., 2023). Therefore, consuming meat alternatives rather than conventional UPF products may offer nutritional benefits, which could be a crucial reason for excluding meat alternatives from the category of UPFs.

7 | CONCLUSION: FUTURE PERSPECTIVE OF MEAT ALTERNATIVES IN UPFS

Plant-based alternatives for meat and meat products are becoming increasingly vital for securing future food resources and addressing environmental concerns.

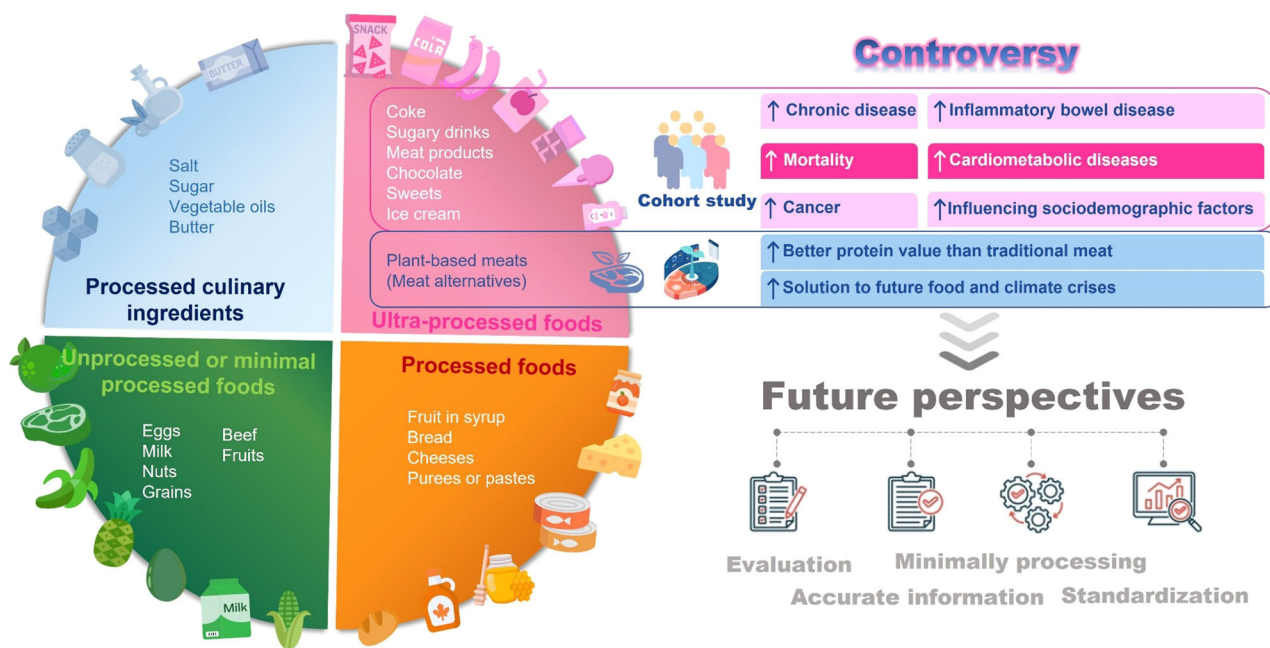


FIGURE 1 Perspective on meat alternatives classified as ultra-processed foods.

However, the classification of these alternatives as UPFs could negatively impact their development. Consequently, it becomes crucial to understand the nutritional, health, and environmental characteristics of these alternatives. This is particularly important considering the use of various additives and numerous processes involved in producing meat alternatives. Therefore, it is controversial to merely criticize all products classified as UPFs that have undergone extensive industrial processing and may pose potential risks to human health. In particular, it is unjustified to criticize plant-based meat alternatives solely because they are categorized as UPFs, as they can play a vital role in addressing future food and climate crises, and they offer a rich source of protein (Figure 1). It is important to note that all food processing is not inherently unhealthy, and minimally processed foods do not encompass all aspects of a healthy diet; UPFs simply serve as convenient and affordable food options. Furthermore, labeling these alternatives as UPFs may hinder the growth of the alternative protein food market, which is crucial for future sustainability. Plant-based alternative foods require processing; however, this processing does not necessarily lower their nutritional quality. Plant-based meat alternatives are often nutritionally superior to other UPFs, and the negative perceptions associated with UPFs do not necessarily apply to these products. Conversely, products that utilize meat alternatives can be nutritionally rich or further enhanced through processing; in addition, it can provide more information regarding meat alternatives.

To address this issue, several suggestions have been proposed. First, research on alternative proteins classified

under subgroups within ultra-processed food classification systems (e.g., the NOVA system) and their associated health risks is very limited. Therefore, more detailed analysis and reassessment are necessary. Second, food classification systems should incorporate evaluation factors pertaining to sustainability and health considerations regarding food and nutrition. Third, the standardization of nutritional profiles of meat alternatives is essential to justify their consumption over conventional animal-derived products. Fourth, clear information demonstrating the positive impact of meat alternatives on public health and societal aspects should be made available. Lastly, to avoid classifying meat alternatives as UPFs, it is necessary to consider producing them with minimal processing, using whole foods, and adding fortification when necessary to ensure a nutritionally complete diet. This may suggest that further studies are needed to justify the exclusion of meat alternatives from the classification system for UPFs, considering their potential for future adaptability and sustainability.

AUTHOR CONTRIBUTIONS

Seung Yun Lee: Conceptualization; investigation; writing—original draft; writing—review and editing.

Da Young Lee: Investigation. **Sun Jin Hur:** Conceptualization; writing—original draft; writing—review and editing.

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea

government (MSIT) (RS-2023-00211920). This work was supported by development fund foundation, Gyeongsang National University, 2024.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interests.

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How to cite this article: Lee, S. Y., Lee, D. Y., & Hur, S. J. (2024). Future perspectives: Current trends and controversies of meat alternatives classified as ultra-processed foods. *Journal of Food Science*, 89, 7022–7033. <https://doi.org/10.1111/1750-3841.17355>