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MEAT CONSUMPTION TRENDS: HEALTH IMPACTS, ALTERNATIVES, AND SUSTAINABILITY PERSPECTIVES

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Abstract
Meat is a valuable source of energy since it contains protein and fat. It is also a source of key vitamins and minerals, such as vitamin B12, iron and zinc. However, high meat consumption can have adverse health and environmental effects. The objective of this paper is to discuss the global trends in consumption of meat and meat substitutes and understand their impacts on human health and the environment. It is accepted that the growing emphasis on sustainability underscores the importance of switching to alternatives, as the traditional meat production system faces substantial environmental and resource limits. Reducing meat consumption is vital in decreasing health and environmental impacts caused by meat production and consumption. Nevertheless, veganism may not be the best solution for all people because nutritious plant-based foods are not readily available particularly in low-income nations. Furthermore, livestock farming provides a significant source of earnings for many low-income households. Further research is required to encourage technical and behavioral improvements, while balancing the environment. Considering the above information, this study provides valuable insights into the consumption trend for meat and meat alternatives, encompassing their strengths, weaknesses, opportunities, and threats.

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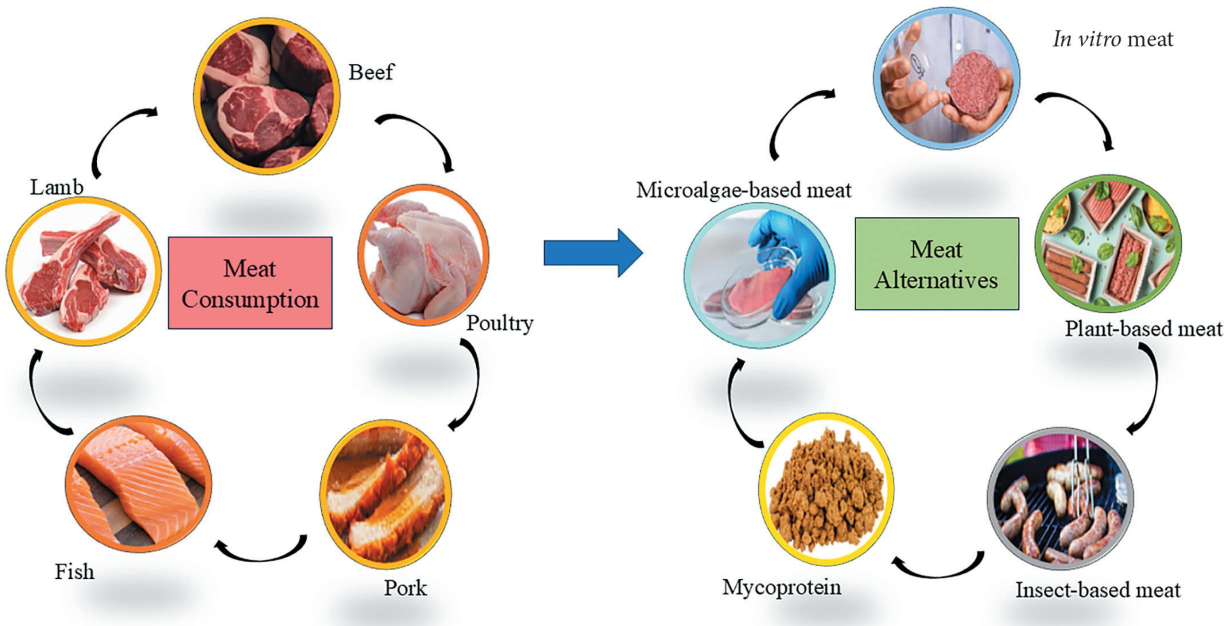
Highlights

- Meat protein is a nutrient-rich source but contributes significantly to environmental pollutants.
- Reliance on conventional meat production should be reduced.
- Demand for meat alternatives is rising; the aim is to meet nutritional needs with lower environmental impact.
- Meat alternatives provide more sustainable option to global food security.
- Food technological innovative production should be revolutionized in the coming decades.

Introduction

Meat is an esteemed protein source that contains all essential amino acids for human health. Fat in meat is a



Graphical abstract

significant energy source and imparts flavor, deliciousness, and delicacy, with its composition varying with the species, quality, and cuts. Other edible parts, such as the liver, kidneys, and offals, are also known for their significant composition of nutrients and minerals that are effectively absorbed by the human body [1]. However, meat is an exceptionally "inefficient" food source. Meat production requires more energy, water, and land than production of other foods. It is also an enormous wellspring of ozone-depleting substance emanations and in this way assumes a significant part in environmental change. According to the European legislation, the term meat is defined as the edible portion obtained from domestic bovine, caprine, ovine, and porcine animals, domestic solipeds, poultry, rabbits, wild and farmed game, as well as some other animals. Meat is identified as the chief source of protein availability with 28 g of protein/per capita/day, trailed by wheat products and dairy products [2]. Over the past 50 years, there has been a notable growth in the meat consumption, which has led to expenses and potential health problems. An estimated 350 million tons of meat are consumed annually worldwide, which results in the annual slaughter of 72 billion animals for human consumption. Also, meat production has doubled since 1988 and tripled since the mid-1960s.

The foods that humans obtain from animal sources are a major provider of essential nutrients. Even though the foods from plant sources can convey the daily nutrients needed by the human body, there should be a sizable number of plants that have to be included in the diet. Some nutrients cannot be digested in the human body whereas they can be digested within the animal body and thus humans can intake nutrients that are in a digestible form from animal products by consuming them. For example, cellulose cannot be digested in the human body but cellulose can be digested by ruminant animals and it turns into products that are thus useful to humans [3]. Society is now having a shift towards diets with more fat, sugar, processed foods, etc., and thus witnessing a situation with a more diseased community. Meat consumption is increasing with increased economic development and thus affecting human health and the environment. This growth in meat consumption has negative impacts on human health and the environment [4]. Meat creates more emission per unit of energy compared to that of plant-based food sources since energy is lost at each trophic level. Within the types of meat, ruminant animals generally prompt a bigger quantity of emissions than non-ruminant warm-blooded creatures, and poultry production ordinarily prompts fewer outflows than warm-blooded animals.

Meat production harms global biodiversity and causes pollution. The resources used in meat production, such as land, energy, and water, could be better employed to grow plant-based foods for humans. The food sector, notably animal-based diets, accounts for 30 % of global greenhouse gas emissions. Livestock husbandry reduces biodiversity, depletes water sources, alters nutrient cycles, and emits greenhouse gasses, all of which have significant consequences for human health and the environment. With a growing worldwide population, demand for meat and animal products is predicted to double by 2050, compounding these difficulties [5,6]. Researchers are looking into the factors that drive people to limit their meat intake and the role that meat substitutes play in reaching this goal. Global meat consumption is linked to chronic diseases such as diabetes, cancer, and cardiovascular problems [7]. Reduced cattle production can efficiently cut greenhouse gas emissions and address concerns including interrupted nitrogen cycles, biodiversity loss, climate change, and pollution [8]. With limited land and water resources, growing meat production is unsustainable. As a result, the development of meat alternatives, such as plant-based, cultured, and insect-based choices, is gaining traction as a feasible solution to fulfill future protein demands [9].

A shift is required from meat and animal-based product consumption to meat alternatives. Recently many plant-based meat alternatives (PBMA), as well as insect-based proteins, are becoming an emerging trend in the market as a suitable choice for meat alternatives. Consumer acceptance of meat alternatives is one of the main challenges [5]. It is considered necessary to reduce meat consumption and thus to identify more sustainable methods for protein intake. Accepting the innovation would permit us to compete with the issues presented by the conventional production of meat. Meat alternatives, especially lab-grown meat, can act as a continuous meat source in the future for space missions. As compared with plant-based foods meat production efficiency is unfavorable. Studies indicated that meat production should be reduced in the future to conserve the environment and human health and also to reduce animal suffering. People consume meat for pleasure, to express their economic and social status, and also for a personal identity beyond its nutritional value. By identifying the meat consumption trend, it is important to propose its impacts on the environment and human health [10], and introducing meat analogs will help in ensuring the health and safety of consumers by thus reducing the climate change caused by commercial meat production [11]. Given the complex nutritional, environmental, and ethical implications associated with rising global meat consumption, there is an urgent need to explore sustainable, health-conscious alternatives. While meat remains a valuable source of high-quality protein and essential nutrients, its production comes at significant ecological and public health costs. In light of growing consumer awareness, environmental pressures, and evolving dietary trends, it becomes crucial to assess the feasibility and acceptance of meat substitutes that can fulfill nutritional needs while minimizing environmental burdens.

Therefore, this research aims to critically examine the health and environmental impacts of conventional meat consumption and to explore the potential of alternative protein sources including plant-based, cultured, and insect-derived options as sustainable substitutes. This study also aims to investigate consumer perceptions and barriers to the adoption of meat alternatives, providing insights into how future dietary transitions can be guided to strike a balance between human health, environmental sustainability, and food security.

Global trends in meat consumption

From the study conducted by the Food and Agricultural Organization, it is estimated that there has been a critical expansion in overall consumption of meat over time and the consumption rate is accelerated by the growing population [5]. At the global level, meat consumption trends increase mainly due to two factors: rising population and rising income in countries [12]. In the analysis conducted from 2000 to 2022, meat consumption patterns have increased noticeably in Indonesia and China with 89 % and 54 % growth, respectively. The growth was much slower in Australia and the United States with 13 % and 8 % respectively, whereas, the meat consumption trends decreased in Japan by 3 %. Figure 1 represents the meat consumption trends in Indonesia, China, Japan, Australia, India and the United States over 22 years to 2022 [5,13,14].

In middle and low-income countries there was an increasing trend for consumption of fat, processed, animal foods. Some factors which are related to an increase in meat consumption include the growing incomes in developing countries. In developed countries, the meat consumption growth has not shown a significant change because it has been high for a long time. Studies evidence that consumers have moved toward white meat in the last two decades. Fish and poultry were marked as the most consumed meat across the world [13]. The trend in meat consumption patterns varies with meat categories and it was found that people have moved to higher consumption of white meat compared to red meat due to its low price [15]. Decreases in price, trade liberalization, extension in the food system, and urbanization are other factors that influence the trends in global meat consumption.

A number of studies suggest that meat intake will increase in the coming years in developing countries with the rise in income and population [13]. There is a need for an approach to create food that represents ecological externalities, while assuring that the worldwide population has **a** sufficient healthy food supply. From the environmental point of view, the future patterns for the food system should be adaptable, sustainable and more efficient [12].

Meat consumption impacts on human health

Daily intake of 50 grams of processed meat has been linked to an 18 % increase in colorectal cancer (CRC) risk, according to the International Agency for Research on Cancer (IARC), which classifies processed meat as carcinogenic and red meat as probably carcinogenic to humans [16]. Processed meats are high in saturated fats and cholesterol, contributing to coronary heart disease, diabetes, and obesity [9]. The WHO recommends limiting red and processed meat intake, especially in high-income countries, and shifting toward more plant-based diets for better health outcomes and sustainability [2]. The American Cancer Society suggests that replacing red meat with poultry or fish may reduce cancer risk [17].

Red and processed meat contains heme iron, which plays an important role in formation of N-nitroso compounds (NOCs) in the gut. It has been postulated that NOCs can damage intestinal lining and potentially lead to CRC [18]. Furthermore, processed meat may contain such compounds as nitrates (which convert to nitrosamines), polycyclic aromatic hydrocarbons (PAHs), and dioxin-like PCBs [18–20]. These compounds have been associated with an increased risk of gastrointestinal, liver, and bladder cancers [18]. Some studies also note that vegetarian and pescatarian diets may lower CRC risk compared to non-vegetarian diets (Table 1) [21,22].

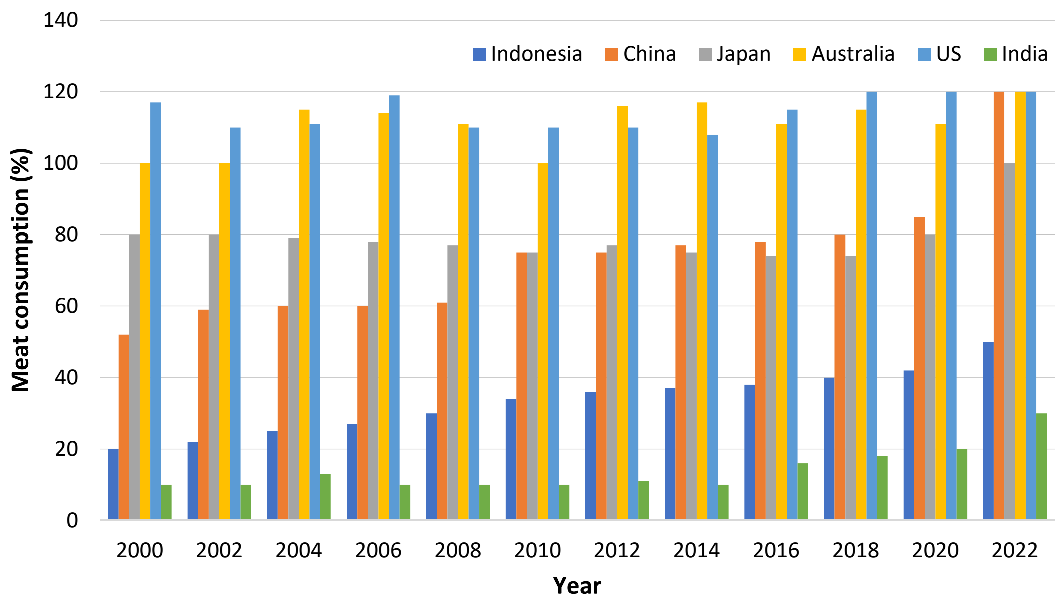


Figure 1. Meat consumption per person from 2000 to 2022

Table 1. Impact of meat consumption on human health

Health impacts	Inference	Reference
Colorectal cancer (CRC)	CRC risk is higher with red meat, such as beef and lamb than with processed meat	[25,26]
Esophageal cancer	Processed meat intake is associated with an incremental chance of esophageal cancer	[29]
Gastric cancer	Processed meat consumption has a greater risk of occurrence of gastric cancer than unprocessed meat	[30]
Bladder cancer	Processed meat was found to be associated with bladder cancer	[31]
Cardiovascular disease	Meat consumption was found to be related to an elevated risk for stroke	[32]
Diabetes type 2	Red meat consumption was found to have a link with the occurrence of diabetes type 2	[33]

In addition to cancer, high consumption of red and processed meats has been linked to an increased risk of type 2 diabetes and cardiovascular diseases. Consuming 50 grams of processed meat daily can raise diabetes risk by up to 51 %, likely due to preservatives and fat content impairing insulin sensitivity [18,23]. Moreover, diets high in saturated fat and cholesterol common in processed meat are known to promote arterial plaque buildup, elevating cardiovascular disease risk, particularly more so with processed than unprocessed meats [24].

In essence, health outcomes related to meat consumption depend largely on meat type, processing level, portion size, and overall dietary context. While plant-based diets have shown benefits in reducing chronic disease risks, well-balanced omnivorous diets that include lean meat and fish can also support optimal health, particularly when integrated with healthy plant based diets, as depicted in Figure 2. Increased intake of meat can lead to a relative risk of developing heart disease. The diets high in red and processed meats show the greatest risk up to 160 % due to their high content of saturated fats, cholesterol, and pro-inflammatory compounds. According to the findings (Figure 2), red meat consumption is associated with a higher relative risk increase (140 %) for heart disease compared to processed meat (125 %). This difference may be attributed to higher levels of heme iron, saturated fats, or other bioactive compounds in unprocessed red meat that influence cardiovascular risk factors [25,26]. In contrast, shifting toward plant-based diets significantly reduces the risk. A general plant-based diet lowers the risk to around 60 %, while a healthy plant-based diet rich in fruits, vegetables, whole grains, legumes, and nuts can cut the risk even further, down to 25 % [27,28].

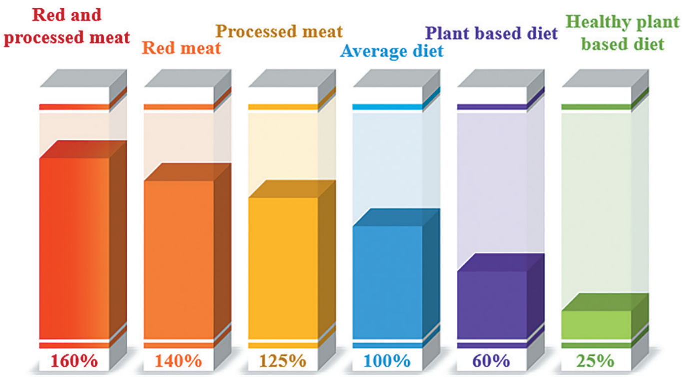


Figure 2. Probability of heart disease based on diets

Impacts on the environment

The environmental implications of meat production, particularly from ruminant livestock such as cattle and sheep, are a growing concern [2]. These animals contribute significantly to greenhouse gas (GHG) emissions, mainly methane, which has a high global warming potential. Studies estimate that by 2050, ruminant meat production could account for over two-thirds of greenhouse gas (GHG) emissions from global agriculture [34]. In addition to GHG emissions, meat production impacts land and water use, biodiversity, and air quality [35]. Intensive livestock farming practices contribute to deforestation, overgrazing, and pollution from animal waste and fertilizers. The majority of pollutants from the environment often detected in meats including polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), polychlorinated naphthalenes (PCNs), are easily absorbed in fats. Beef production, for instance, requires considerably more land and water compared to plant-based alternatives, such as grains and legumes [36,37]. The GHG contribution to a variety of diets is shown in Figure 3.

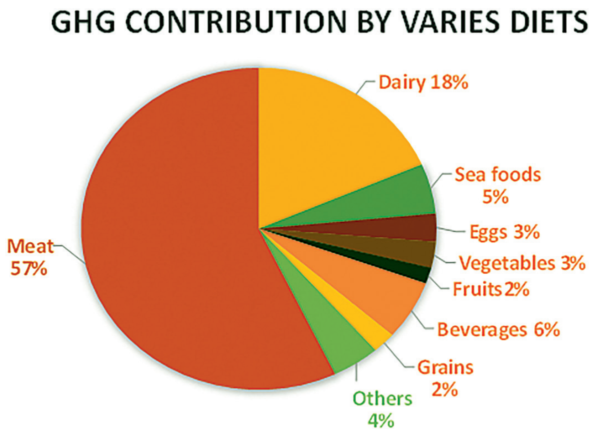


Figure 3. GHG contribution by various products

Benefits of meat consumption

Nevertheless, it is important to recognize that meat, when consumed in moderation and sourced sustainably, can play a beneficial role in both nutrition and the environment. Rather than advocating for complete elimination, a balanced consumption and responsible production are emphasized as more realistic and effective approaches for achieving public health and environmental goals. Nutritionally, meat, especially lean and unprocessed varieties, remains a rich and efficient source of essential nutrients. It offers high-quality, complete protein along with bioavailable iron, zinc, selenium, and vitamin B_{12}, all of which are vital for maintaining muscle mass, immune health, cognitive function, and preventing nutrient deficiencies. These benefits are particularly important for vulnerable populations such as children, pregnant women, and the elderly, where deficiencies in these nutrients can lead to long-term health consequences [38,39].

In fact, including moderate amounts of lean red meat or poultry in a balanced diet has been shown to improve satiety and aid in weight management without a negative effect on cardiovascular health. Clinical studies, such as those examining the DASH (Dietary Approaches to Stop Hypertension) diet, have demonstrated that lean meats can be part of a heart-healthy eating pattern, helping to control blood pressure and lipid levels when consumed alongside plenty of fruits, vegetables, and whole grains [40].

From an environmental standpoint, not all livestock systems are equal in their impact. When managed sustainably, livestock can contribute positively to ecosystems. Practices such as rotational grazing and agroecological animal husbandry can help restore soil health, sequester carbon, and enhance biodiversity [41]. In many parts of the world, especially in low- and middle-income countries, livestock are not just a food source; they play vital roles in livelihoods, nutrient recycling, and farm resilience [42].

Furthermore, innovations in animal nutrition, such as low-emission feed additives, and the adoption of waste-to-energy systems are helping reduce the carbon footprint of meat production. These sustainable strategies show that with thoughtful policy and technological advancement, meat can be produced in a way that supports both food security and environmental stewardship [43].

Ultimately, the conversation around meat should move beyond extremes. Rather than eliminating meat entirely, encouraging mindful consumption focused on quality, source, and quantity can help strike a balance between nutritional needs and environmental priorities. Choosing lean, unprocessed meats, reducing portion sizes, and supporting ethical farming practices are practical steps individuals can take toward better health and a more sustainable food system.

Meat alternative sources

Many studies revealed that 30 % of GHG emissions occur from the food sector, mainly the animal-based food production system, causing all kinds of biodiversity losses. FAO has proposed that livestock handling is the major contributor to climate change. Therefore, reducing animal meat consumption is considered important. To this end, a shift is required from conventional meat-based products to meat analogs. Research from the past reflected that consumers do not know about the enormous effect that the consumption of meat has on the environment. A large part of customers does not consider eating meat substitutes even though a minority of them have consideration for it [44].

Meat alternatives are also known as meat analogs, faux meat, fake meat, mock meat, meat substitutes, imitation meat, and meat surrogates. Technologically a transition from meat-to-meat alternatives can be obtained by "protein transition" [45]. Studies evaluated that soy protein has high health benefits practically identical to animal protein and represents a great base for meat substitutes. In the 1960s, soy protein was first presented in the US market as a significant meat analog in the form of tofu and fermented soy cake. As an alternative to meat, consumers consider mainly plant-based meat alternatives (PBMA). In addition to plant-based meat alternatives, other meat analogs include *in vitro* meat, insect-based protein sources, microalgae-based meat, and mycoprotein-based food products [46].

***In vitro* meat**

In the current scenario, livestock meat production is increasing day by day due to its nutritional importance and increasing consumption of meat by the population. A new technology to develop meat in the laboratory called *in vitro* meat, cultured meat or lab meat evolved as a substitute for conventional meat. This technology operates on the principles of tissue engineering by isolating stem cells from livestock (e. g., cattle, pigs, or sheep) and culturing them in a bioreactor. The bioreactor provides a growth medium enriched with nutrients and growth factors, enabling the cells to proliferate and differentiate into mature muscle tissue, ultimately forming in vitro meat [36]. Thus, it includes a new method of developing meat from animal muscles to avoid slaughtering process [47].

The proposal behind *in vitro* meat came from the idea put forward by Winston Churchill. He once suggested that "We shall escape the absurdity of growing a whole chicken in order to eat the breast or wing, by growing these parts separately under a suitable medium". Later Frederick Edwin Smith foresaw a future where raising entire cattle for meat would become unnecessary. He suggested that from a single starter steak, it would be possible to cultivate vast quantities of equally tender and flavorful meat [36].

The world's first *in vitro* meat was cooked and tested by a sensory panel in London in 2013. The *in vitro* meat was more like white meat, and thus some amount of beetroot juice and saffron were added to give the meat its particular color. The panelists found that the cultured meat tasted quite similar to animal meat.

Many kinds of research have been conducted by NASA on *in vitro* meat to make it a "long-term food" available for astronauts [48]. The production of *in vitro* meat has many advantages, including health, financial, environmental, and animal welfare advantages, over traditional meat. Studies revealed that *in vitro* technology is used for the production of steak, sausages, nuggets, etc., and researchers are still working on developing meat for commercial use [36].

Techniques for production of in vitro meat

The development of meat from muscle cells with the technology of tissue engineering without rearing animals is called *in vitro* meat production. Two technical methods are used for developing *in vitro* meat in laboratories such as self-organizing technique and scaffold-based technology [48].

Self-organizing technique

The method arose with the application of tissue engineering by Benjaminson, Gilchriest, and Lorenz to develop meat in the 21st century. This method is used for the production of structured muscle tissue. They first developed this technique experimentally by isolating the explants from a golden fish and culturing them in a proper nutrient medium and identified the expansion in the growth of muscle explants. These isolated muscle fibers contain all components in correct proportion thus mimicking an *in vivo* meat structure. However, the explants lack blood circulation, which exert a negative impact on substantial growth and thus this method is unable to produce large amounts of meat without vascularization [36]. Nevertheless, meat developed with this process will have a well-organized 3-D structure [47].

Scaffold-based technology

This technique consists of culturing stem cells isolated from farm animals in appropriate bioreactors [47]. The embryonic myoblasts are multiplied, then attached to a scaffold and perfused with a nutrient-rich culture medium. These culturing results in myofibers formation and these myofibers may then be processed and utilized as *in vitro* meat. Figure 4 represents the production process of *in vitro* meat by scaffold-based technique. Scaffold-based techniques are applied for the production of boneless meats with soft consistency, but structured meats such as steaks cannot be produced using this technique [36].

Benefits of in vitro meat

In vitro meat was developed to reduce animal suffering and to satisfy the need of meat-eaters with an alternative to conventional meat. In light of the sizable adverse consequences of current meat production for climate and human well-being, a reasonable solution lies with *in vitro* meat production [36]. The production of *in vitro* meat offers health and environmental benefits by lessening ecological contamination, as well as water and land utilization related to current meat production methods [49,50]. The nutritional composition of cultured meat can be redesigned and developed with suitable needs.

In vitro meat manufacturing reduces the GHG emission and carbon footprint of meat by reducing the rearing of animals for food. Food scarcity, increased risk of cancer, and many other diseases that occur due to the consumption of conventional meat can be eliminated by utilization of *in vitro* meat. The fat and other nutrient content in the meat can be controlled in cultured meat and unhealthy saturated fats can be replaced in it. The *in vitro* meat

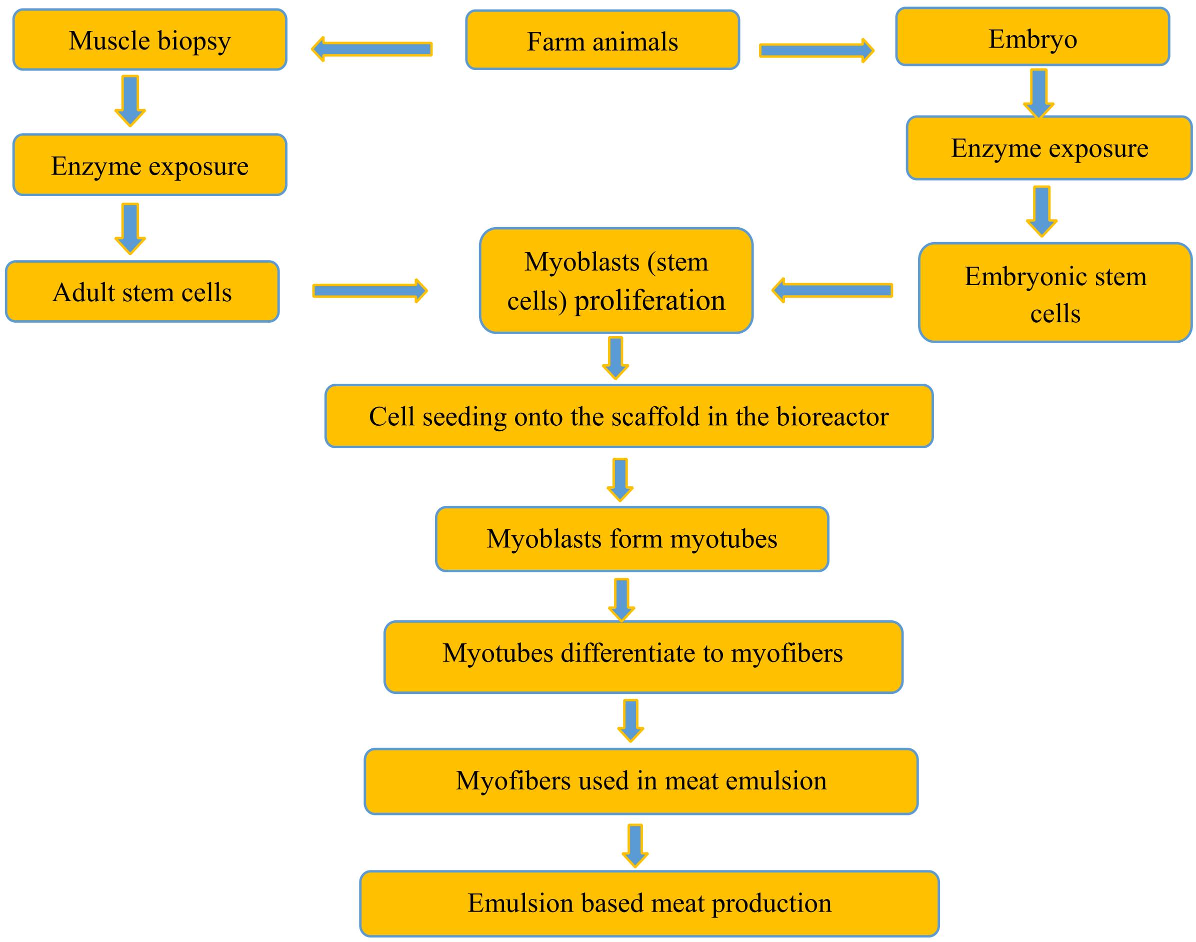


Figure 4. The production process of *in vitro* meat by scaffold-based technique [36]

production system is time-efficient and can produce meat within weeks when compared with conventional meat production from animals, which takes months to years. Many traditional animal slaughtering methods that are used to meet the increasing demand for meat consumption require high amounts of resources. Around 70% of fresh water and 20% of energy utilization is straightforwardly or in a roundabout way used for food manufacturing, of which an impressive extent is utilized for the rendering of meat. *In vitro* meat production reduces land use and biodiversity losses because it is built up vertically by utilizing less land area when compared with land used for grazing animals Researchers have found that 80% of the land and water resources used are reduced by utilizing *in vitro* meat. This also lowers GHG emissions to 80–95% [36].

Another important issue is food safety. The condition of food poisoning occurs through the consumption of meat slaughtered and handled in an unhygienic environment. Many food-borne diseases, including zoonotic diseases, that spread through commercial meat products can be prevented by the consumption of lab meat [51]. In addition, the risk of the presence of other hazards, for example hormones, can be reduced through this advanced technology [36,39,40]). *In vitro* meat is a good replacer for palates, steaks, etc. in the sense of flavor, taste, and tenderness. This technology can generate meat of consumer preferences by utilizing very low energy and is a time-efficient process. Theoretically, the *in vitro* meat developed using a single farm animal may create the world's meat supply [36].

Challenges in developing in vitro meat

The major challenge with *in vitro* meat is its acceptability as a meat substitute. A survey conducted globally on the acceptability of *in vitro* meat revealed that 80% of the US population was not willing to consume *in vitro* meat, but in the UK 68% of the respondents said that they would eat *in vitro* meat. The major disadvantage of *in vitro* meat is the absence of the natural pigment myoglobin, which gives the red color to meat, and the lack of minerals that are abundant in red meat [47].

Another challenge in developing *in vitro* meat is the mimicking of natural meat flavor. The technical challenge faced in the manufacturing of *in vitro* meat is the isolation of correct stem cells from animals [52,53].

Cultured meat is an unpreventable fate of humankind, but the high cost of manufacturing is a significant barrier to development. The cost of manufacturing cultured meat is high and thus this process is deliberate in society [36]. The growth media for meat should be less costly and of plant origin because it is more realistic than growth media made from animal sources. However, *in vitro* meat developed in this plant-based growth medium may cause an allergic reaction in some consumers [51].

Maintenance of the growth medium for stem cell culture was found to be a great challenge. Finally, the most important challenge is the so-called "yuck factor". This is the reluctance of consumers to take up with the idea of eating unnatural meat that is developed in the lab [47,54].

Plant-based meat alternatives (PBMA)

Protein-rich plants such as soybean, oilseeds, legumes, wheat, and fungi are well-known meat analogs [55]. The technologies used for the manufacturing of PBMA include shear cell technology and extrusion technology. Some of the common plants with their proteins that can be used as a meat substitute are illustrated in Table 2. Currently, the market for plant-based meat analogs is expanding with expanding social requests, and consistent endeavors are being taken to work on enhancing the sensorial characteristics of PBMA. PBMA has been regarded as the best meat analogs in the market recently [56,57]. Beyond Burger (BB) and Impossible Burger (IB) are the major two companies that have developed plant-based meats and they use soy protein, and wheat protein as the major alternatives [56].

Table 2. Plants with their proteins that can be used as meat substitutes

Plant	Protein
Soybeans	ß-conglycinin
Oilseeds	Legumin, albumin, globulin, glutenin
Wheat rye, barley	Gluten (Glutenin, gliadins)
Legumes	Glycinin, vicilin
Filamentous fungi	Mycoproteins

Benefits of PBMA

According to the nutritional sources, soy protein and wheat gluten are the finest alternatives [58]. Wheat provides 8–17.5% protein, primarily in the form of gluten, and is deemed safe to consume. Technologies have effectively isolated gluten from wheat while preserving its structure, allowing it to be easily combined with other substances to create meat substitutes. On the other hand, soy protein has acquired consumer acceptability as a superior meat substitute due to its high protein content, environmental benefits, and nutritional value, which includes lipids, carbohydrates, iron, zinc, calcium, and B vitamins [59,60].

A study conducted by Bohrer [56] on the protein content in conventional meat in comparison with plant-based meat alternatives revealed that PBMA contains approximately the same amount of protein as traditional meat. H analyzed beef patty, pork ham, meatballs, and chicken nuggets and estimated that beef patty contains 23.3 g of proteins, while plant-based patty contains around 16.8–25 g of proteins. PBMA of ham, meatballs, and nuggets was also found to have similar amounts of proteins and other nutritional components when compared to the conventional meat products. Figure 5 illustrates the comparative study on protein content in conventional meat and plant-based meat alternatives.

PBMA is also an alternative for such consumers who will not consume meat due to ethical beliefs. While considering the nutritional aspects, PBMA was found to balance all the nutrients in traditional meat. Currently, consumers also have an increasing consideration for animal welfare

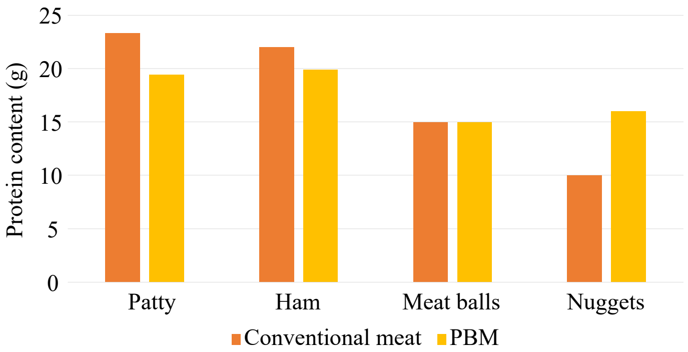


Figure 5. Comparison of protein content in conventional meat products and PBMA

and thus PBMA can show a great expansion in the market in the future [6]. Furthermore, plant food sources have a wide range of phytochemicals that play a significant role in human health. PBMA has less GHG emissions when compared with meat production and livestock handling. It has been stated that comparable amounts of protein, iron, and vitamin A can be acquired from delicately chosen plant-based foods at a lower carbon footprint when contrasted with meat consumption [35]. The lower carbon impression of plant-based meat analogs is promoted as a principal justification behind opting for PBMA [58].

Challenges of PBMA

Even though plant-based meat alternatives have good nutritive value, acceptability remains an obstacle among consumers. The major challenge for developing PBMA consists of meeting all the textural and sensory parameters of traditional meat. Various techniques including thermoplastic extrusion, spinning, and steam texturization are applied to plant proteins to develop texture and appearance [59]. Technologies are applied in extracting meat flavors from similar components and inducing them into plant meat. In addition, different flavor enhancers and fats are added during the manufacture of plant-based meat analogs [54].

Color is another important parameter apart from flavor for plant meat, which has a role in consumer perception [6]. Research has suggested that the PBMA should have a color resembling that of raw meat or cooked meat [59]. To bring the PBMA its particular color similar to conventional meat, beetroot juice, and tomato juice are added during its manufacture [54]. Some meat analogs are developed with added leghemoglobin, which has particular structural characteristics similar to hemoglobin that imparts a red color to meat. The addition of leghemoglobin imparts cooked meat color to meat substitute. Leghemoglobin was also identified to impart distinctive conventional meat flavor to PBMA [61].

During the development of PBMA, its safety should be ensured before marketing. Some anti-nutritional factors are present in meat analogs regardless of the many nutritional factors present in them. Some of the plant proteins can cause an allergic response in consumers. Therefore, ensuring the safety of plant meat is a great challenge. The challenges faced during the manufacturing of PBMA can be overcome in the future by applying advanced technologies [6].

Insect-based meat alternatives

In certain countries in Africa, Southeast Asia, and South America, the habit of eating insects, known as entomophagy, has a lengthy history extending back around 3000 years [62,63]. These societies have adopted the ingestion of insects as a means of meeting their daily protein and amino acid needs. With over 5.5 million recognized bug species on Earth, they have access to a mind-boggling 2000 insects for eating source [64,65]. Researchers discovered that insects such as grasshoppers, crickets, caterpillars, ants, bees, beetles, planthoppers, leafhoppers, and dragonflies are regularly consumed and provide a higher protein source than typical meat [66]. Insect food sources are equivalent or superior to conventional meat in terms of energy and protein [46]. Insects are also a rich source of iron, zinc, fat, and several vitamins [67].

It is worth mentioning that the protein level varies based on the insect species and stage of development, with the larval stage typically possessing a substantial amount of protein.

However, as a food component, the consumption of insects is very low among consumers because of the acceptability criteria. Recently due to the increasing global threats by meat consumption, meat alternatives are of much importance [68]. Currently, with this increasing demand for meat alternatives as a protein source, insect-based foods are an emerging trend. Research revealed that in the future the insect-based food market will steadily increase [69].

Benefits

Entomophagy is an environmentally friendly choice and it reduces GHG emissions and maintains the land degradation caused by the raising of animals for food [70]. Studies evidenced that insects are a great source of protein and thus it is a good alternative for meat. The protein percentage varies with species and stage of development. Some of the edible insect species and their nutritional composition are represented in Table 3.

Table 3. Edible insect species with their nutritional composition

Edible insects	Protein %	Fat %	Fiber %	Ash %	Energy content (kcal/100g)
Orthoptera (grasshoppers, crickets)	61.3	13.41	9.55	3.85	426.25
Blattodea (cockroaches)	57.30	29.90	5.31	2.94	—
Odonata (dragonflies, damselflies)	55.23	19.83	11.79	5.53	431.33
Diptera (flies)	49.48	22.75	13.56	10.31	409.78
Hemiptera (true bugs)	48.33	30.26	12.40	5.03	478.99
Hymenoptera (ants, bees)	46.47	25.09	5.71	3.51	484.45
Lepidoptera (butterflies, moths)	45.38	27.66	6.60	4.51	508.89
Coleoptera (beetles, grubs)	40.69	33.40	10.74	5.07	490.30

As compared with plant proteins, insect proteins have high bioavailability and more essential amino acids as well as proteins and thus insect proteins can serve as a major protein source in the diet. Some of the unique insect amino acids such as lysine, threonine, and tryptophan are only obtained from insect sources [71]. The utilization of insect proteins is beneficial not only due to their high nutritional content but also due to the fewer requirements of energy, water, land, and feed when compared with the rearing of animals for food [71,72].

Challenges

Not all insects are safe for human consumption and reports evidence that nutritional deficiencies and medical illness are also associated with the consumption of some species of insects. Ataxic syndromes were reported in Nigeria through the consumption of *Anaphe venata* [70]. The major challenge is the acceptability of insects as food for consumers. Mass production of insects is also a great challenge regarding the breeding and processing time of insects for consumption.

Food and Drug Administration (FDA) has implemented certain norms with regard to the processing of insects for a food source and proposed that insects for food sources should be cultivated specifically for the purpose of human consumption and manufacturers should ensure the 'wholesomeness' of a product, that is they should ensure that the product is free from parasites, microbes, and dirt [46].

Regardless of constant efforts to expand insect proteins in the market, their consumption may not turn into a standard eating choice [69]. Having skeptical attitude towards novel foods, consumers hesitate to consume insect proteins [68]. Consumption of insects remains the main challenge because people consider insects as unpleasing, dirty, harmful creatures and thus avoid their consumption. The consumers' unacceptance of insects as an alternative to meat is mainly due to food neophobia. Nonetheless, there are many antinutritional factors, toxic substances, and allergens present in insects that should be eliminated before their utilization as food, and thus insect protein utilization remains a challenging factor [6].

Fungi-based meat alternatives (Mycoprotein)

Mycoprotein is produced from a naturally occurring filamentous fungus *Fusarium venenatum*. In 1967, a strain of *F. venenatum* was found to be a potential source of protein. Later, *F. venenatum* was chosen as the most suitable organism for mycoprotein synthesis by the Rank Hovis McDougall (RHM) Company in England. The generic name mycoprotein was specified for the ribonucleic acid-reduced biomass comprising hyphae (cells) of the organism *F. venenatum* A3/5(ATCC PTA-2684) obtained using a continuous fermentation system. Following MFAFF certification, mycoprotein was marketed under the UK trade name "Quorn" [73–77]. It has nutritional benefits for human health being an excellent source of protein and fiber.

Mycoprotein production

The continuous flow system is the most frequent economic production method for biomass-related products, with a substantial dilution rate. In a constant flow environment (maintained at 28–30 °C and a pH of 6.0), fungi can multiply to the desired levels with minimal amounts of glucose and ammonium, i. e., carbon and nitrogen sources respectively. The biomass concentration and the flow rate can be assessed by evaluating and monitoring the growth in carbon dioxide (CO_2) levels. Following these conditions, a growth rate of 0.17 to 0.20 per hour and a production outcome of 300 to 350 kg per hour of *Fusarium venenatum* A3/5 biomass can be attained. The biomass is checked (every six hours) for hazardous contamination including mycotoxins. The harvested fungal biomass undergoes a step to reduce RNA content, including heating at 72 to 74 °C for 30 to 45 minutes to lower the RNA levels to below 2 %, making it safe for human consumption. Subsequently, in this RNA reduction process, the broth is subjected to an additional heat treatment at 90 °C and then centrifuged to obtain dry biomass with a solid content exceeding 20 % (W/V). Besides, the mycoprotein biomass undergoes a series of processes involving steaming, chilling, and freezing to achieve the meat-like texture characteristic of Quorn products (Figure. 6). This translates into a complex network of mycoprotein hyphae that reveals a high level of

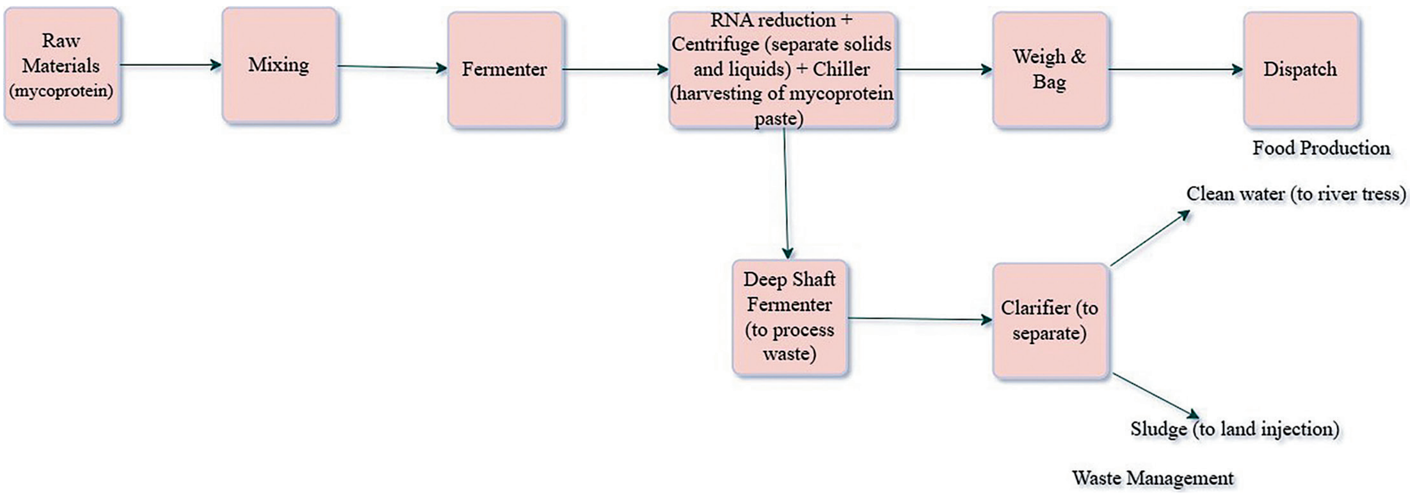


Figure 6. Process flowchart to produce Quorn mycoprotein [77]

fibrosity, analogous to the texture of chicken breast when viewed under a microscope. Presently, mycoprotein is used in a diverse array of products, ranging from frozen to refrigerated options, including Quorn mince, pieces, nuggets, steaks, sausages, fillets, fish fingers, and burgers [77].

Benefits

Mycoprotein is important for a healthy diet because of its high protein content, enhanced fiber, and low saturated fatty acid concentration. According to experimental investigations, mycoprotein may give various nutritional benefits, including increased satiety and better regulation of blood sugar and cholesterol levels [76]. If mycoprotein is to be used in main course dishes, it must be of high protein quality. Mycoprotein has all required amino acids. It contains 6 g of fiber per 100 g, indicating that it is "high in fiber" according to the European Commission. The natural dietary fiber of this fungal protein consists of 12 % soluble and 88 % insoluble fibers, with a small amount of chitin and a high concentration of glucan (forming a "fibrous chitin-glucan matrix" in the small intestine) [78,79].

The α-glucans (linear and branched), from grains and yeast help in fat metabolism and immune system function. Mycoprotein has an energy composition that is roughly one-third fat due to some easily available carbohydrates. Typically, mycoprotein contains less than 1.5 g of saturated long and short-chain fatty acids per 100 g solid. This fungal protein is high in monounsaturated and polyunsaturated fatty acids. It contains water-soluble B vitamins such as pyridoxine (0.1 mg), folate (114 µg), and cobalamin (0.72 µg). It also has a high concentration of zinc, phosphorus, calcium, iron, potassium, and other minerals [77,78].

Challenges

Mycoprotein, derived from the fungus *Fusarium venenatum*, faces multiple challenges in both its production and consumer uptake at present. A significant concern is the production cost. The existing techniques for farming mycoprotein tend to be quite costly, leading to prices that frequently align with those of conventional meat products. This mount price may demoralize consumers from considering mycoprotein as a feasible alternative, hence restricting its market reach and rate of economic growth. Another major challenge is the insufficient research on sensory attributes such as appearance, texture, and mouthfeel. Although mycoprotein is recognized for its meat-like texture, the lack of comprehensive studies on these sensory qualities can hinder consumer acceptance. A lot of people select meat substitutes based on their sensory experiences. Therefore, it may be difficult to develop a position in the market unless there is a more thorough understanding of how mycoprotein measures up against traditional meats in these aspects.

Moreover, the nutritional composition of the primary materials used in mycoprotein production presents a challenge. While lignocellulosic materials are suitable for fermentation, it is crucial to identify appropriate byproducts generated from agricultural and industrial processes that offer advantageous nutritional profiles for efficient products. This challenge is further complicated by the necessity to maintain environmental sustainability, as effectively utilizing agricultural waste could significantly lower the carbon footprint linked to mycoprotein production [80]. Consumer acceptance is also a concern, particularly regarding allergic reactions. Although mycoprotein is generally considered safe, there have been instances of adverse reactions, such as nausea and vomiting, in some individuals. This can lead to hesitation among potential consumers, especially those with allergies or sensitivities. Despite the rarity of such reactions, the perception of risk can influence consumer decisions [76].

Finally, mycoprotein encounters strong competition from an increasing variety of plant-based protein alternatives. As consumer preferences evolve towards a broader range of protein sources, mycoprotein needs to set itself apart through its taste, texture, and nutritional advantages to gain a larger market share. Tackling these challenges is essential for the future expansion and acceptance of mycoprotein as a sustainable and nutritious food option.

Microalgae-based meat alternatives

Microalgae are minute photosynthetic organisms that live mainly in aquatic environments, both freshwater and marine. They are mostly unicellular and belong to several taxonomic families, being a diverse and important part of ecosystems. Microalgae are essential not only due to their ecological functions but also due to their prospective applications in a variety of sectors. They are being investigated as sources of biofuels, nutraceuticals, and biopharmaceuticals because of their substantial amount of useful chemicals such as proteins, fatty acids, antioxidants, and pigments [81]. Furthermore, microalgae are regarded as a sustainable resource for food production, particularly in the creation of meat substitutes and other functional foods. Microalgae-based meat analogs are meat substitutes that use microalgae as a main ingredient. These products are intended to replicate the flavor, texture, and nutritional profile of traditional meat while providing a more sustainable and healthier alternative. Microalgae are noted for their high protein content, which can surpass 70 % in dry matter, and their rich composition of important amino acids, making them a viable resource for developing meat substitutes [82].

Microalgae production

Figure 7 depicts various technological pathways for creating microalgae-based meat analogs. Both microalgal biomass and protein extracts can be evaluated for texturing purposes. While the direct use of microalgal biomass is a cost-effective option, certain species may have rigid cell walls and high oil content that can hinder texturing and lower nutrient bioavailability. Consequently, protein extracts can serve as a complementary material for extrusion

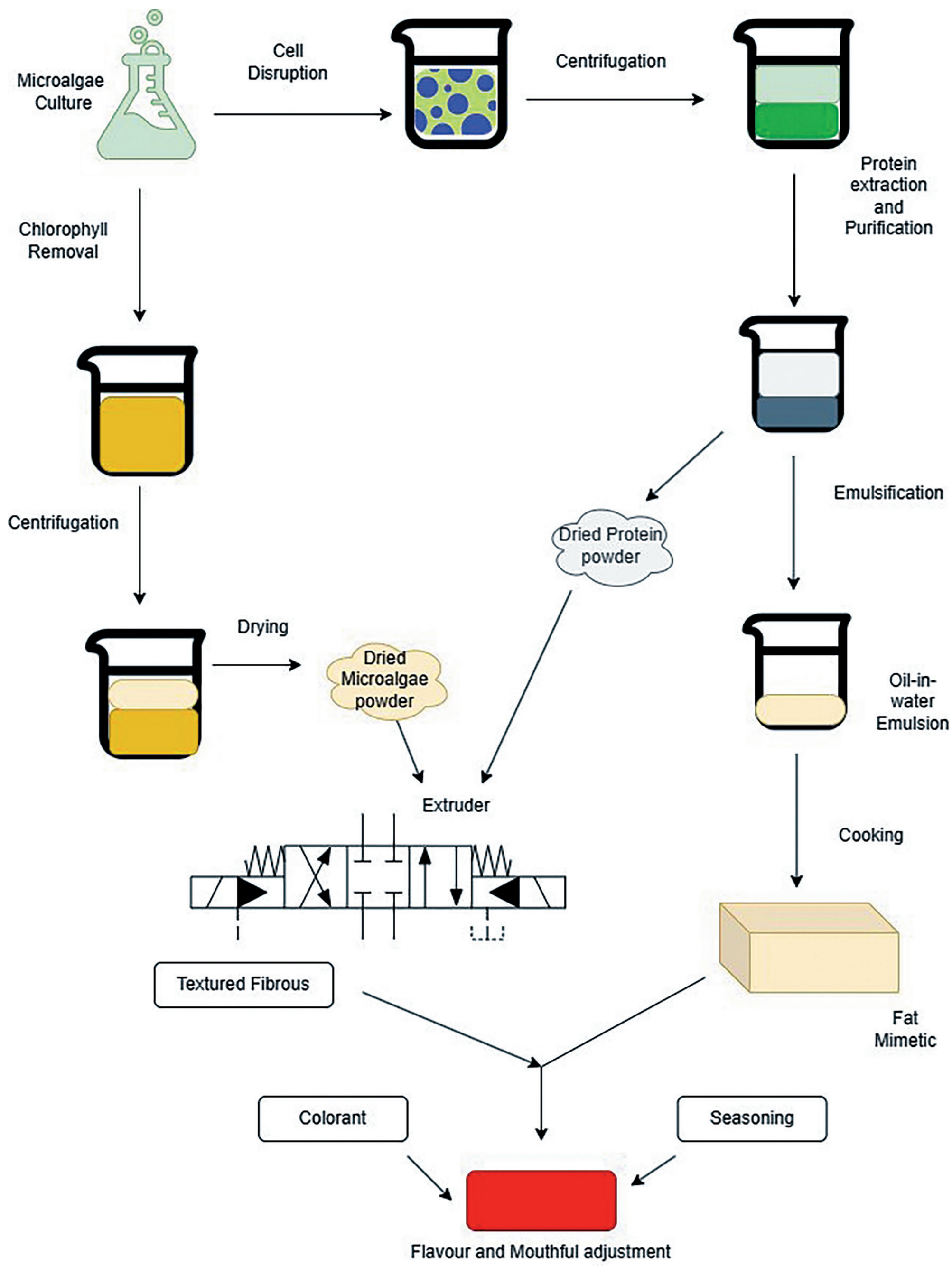


Figure 7. Schematic diagram of technical routes to produce microalgae-based meat

processes. After texturing, the resulting fibrous products and fat substitutes can be combined through emulsification [81]. Another critical aspect of producing meat analogs involves flavor adjustment. Different seasonings and colorants can be tested at various stages of food processing to identify beneficial chemical reactions. Additionally, the diverse compounds found in microalgae may serve as a source for novel chemical reactions, potentially leading to new flavors but also introducing new risks. Therefore, while microalgae as food ingredients offer numerous opportunities, they also pose risks that necessitate thorough investigation.

Microalgae biomass harvesting and processing

Harvesting microalgae biomass is a major challenge in production. Common ways include centrifugation, flocculation, and filtration [83].

Flocculation

A popular technique for harvesting microalgae is favored for its low cost, time efficiency, and high effectiveness in recovering algal biomass. This technique involves adding chemicals to aggregate microalgae cells, making them easier to separate. There are two main categories of flocculants: chemical flocculants and bio-flocculants. Studies indicate that bio-flocculants are safer, more economical, and environmentally friendly. Examples of bio-flocculants include acrylic acid and chitosan, which can occur naturally or be produced artificially [84,85].

Centrifugation

This method separates microalgae from the culture medium based on the density differences but can be energy-intensive. Harvesting microalgae through centrifugation is recognized for its high separation efficiency, exceeding

90 %. The most commonly used type of centrifuge for producing high-quality algae is the disk stack centrifuge. However, this method comes with significant operational energy demands [86]. According to pricing information, a typical dewatering centrifuge costs approximately RM 18,000, while a disk stack centrifuge is priced around RM 45,000 [84]. The high energy requirements associated with these centrifuges can lead to substantial operational costs. For instance, a disk stack centrifuge typically consumes about 1 kWh/m³ of feed. Given an average energy rate of RM 0.30 per kWh for industrial and agricultural applications, the cost to separate 1 m³ of feed would be RM 0.30, which is five times higher than the cost associated with flocculation. Similar to flotation methods, this high cost could be a disadvantage in the long term unless there is access to affordable and reliable renewable energy sources.

Flotation

Flotation methods, such as dissolved air flotation (DAF) and dispersed air flotation (DiAF), offer several benefits, including low initial capital costs, compact operational space, and rapid, efficient large-scale harvesting. These processes often utilize surfactants or flocculants to enhance harvesting effectiveness. However, a significant drawback is their high energy consumption, which leads to increased operational costs. Without access to affordable and reliable renewable energy, the energy expenses associated with these systems could become a major obstacle to their widespread adoption. Microalgae can also be harvested through membrane filtration techniques, which can be effective but may require pre-treatment to avoid clogging [83].

Benefits

Microalgae are gaining attention as a promising ingredient for meat alternatives because of their excellent nutritional profile, sustainable cultivation, and health advantages. It is a valuable source of carbon compounds that can be used in various applications, including biofuels, health supplements, pharmaceuticals, and cosmetics. They play a role in wastewater treatment and help mitigate atmospheric CO_2 levels. Besides, microalgae can be a source of several bioproducts, such as polysaccharides, lipids, pigments, proteins, vitamins, bioactive compounds, and antioxidants, which provide the consumer with a wide range of health benefits. The incorporation of microalgae in meat alternatives can improve their nutritional profile, making them a healthier option [87].

Lately, microalgae are regarded as a novel protein source for meat analogs. Microalgae proteins exhibit emulsifying, foaming, gelation, and solubility characteristics, comparable to those of other plant-based proteins such as soy, commonly used in meat formulations. Likewise, microalgae can enhance both the texture and flavor of meat alternatives. They are exceptional natural nutrient sources and can improve the overall quality of food products by diminishing the reliance on chemical preservatives. Microalgae production is regarded as more environmentally friendly than traditional cattle husbandry. Microalgae culture needs less land and water and can be farmed in a variety of settings, including non-arable terrain. Furthermore, microalgae can absorb carbon dioxide as they grow, helping to reduce greenhouse gas emissions. Studies have indicated that high moisture extruded microalgae products may be more sustainable than traditional meats such as pork and beef [87].

Challenges

Increasing the production of microalgae presents several challenges, particularly in optimizing both upstream and downstream processes. These challenges can be categorized into social inclusion, technological limitations, sensory properties, and commercial factors [88].

Consumer acceptance

One of the most significant challenges for microalgae-based meat substitutes is consumer acceptance. Consumers frequently form preconceived beliefs about algae, connecting them with unpleasant flavors or textures. This attitude can lead to reluctance to try microalgae products, regardless of their nutritional benefits. To overcome this obstacle, it is vital to educate customers about the positive impacts of microalgae and design marketing techniques that emphasize their environmental and medical advantages [83].

Technological limitations

The technological obstacles to converting microalgae into meat alternatives are enormous. Present techniques for texturizing plant biomass are still in the initial stages of research and development. This includes developing practical strategies to improve the texture and mouthfeel of microalgae, making them more palatable as meat alternatives. Furthermore, unpleasant scents and colors commonly seen in algae must be treated to improve consumer acceptance [88].

Sensory properties

Microalgae frequently have undesirable sensory characteristics, such as a grassy flavor or a fishy odor, which can repel customers. These sensory features can be unpleasant; thus, producers must devise methods to disguise or erase these flavors and colors. Creating formulations that blend the health advantages of microalgae with suitable sensory characteristics is critical for market success [83].

Commercial factors

Manufacturing microalgae-based meat replacements at a commercially viable scale is challenging. Scaling up production to meet customer demand while maintaining rates comparable with conventional meat products is difficult. Existing cultivation technologies may lack the requisite efficiency to enable the widespread use of microalgae in food products on a commercially feasible scale. To address this, continuous research and innovation are imperative to fully unlock the potential of microalgae in the realm of meat substitutes [82].

The overall benefits and challenges of each meat alternative are given in the Table 4 below.

Table 4. Benefits and challenges of meat alternatives

Meat Alternatives	Benefits	Challenges	References
In vitro meat	➢ Disease-free Meat: Production of healthy and sustainable meat with a favorable wholesome profile under controlled conditions. ➢ Animal Welfare: Elimination of the need for traditional animal slaughter, humane meat production ➢ Responsible Production: Potential to reduce nutritional deficiencies, foodborne illnesses, and antibiotic-resistant pathogen strains. ➢ Environmental Impact: Lowers greenhouse gas emissions, and depletion of water and land resources. ➢ Source of Protein: Cultured animal cells offer diverse protein sources. ➢ Availability: Meets the increasing global demand for meat while minimizing the strain on limited resources.	➢ Consumer Acceptance: Challenges to mimic natural meat flavor, texture, and nutritional composition without impacting safety or consumer acceptance as a meat substitute. ➢ Technological Challenges: The development of appropriate isolation methods for specific stem cells and suitable culture media is necessary. ➢ Health concerns: Plant-based media for cultivation may induce allergy reactions in some consumers. ➢ Industrial Scalability and Cost: Scaling up production in commercial bioreactors is crucial and not economically viable for large-scale production due to high manufacturing costs.	[36]
Plant-based meat	➢ Nutritional Benefits: Good source of vitamins, minerals, and protein (soy protein and wheat gluten). ➢ Eco-friendly: Moving away from traditional meat production can help conserve land, reduce greenhouse gas emissions, and minimize water usage. ➢ Beneficial for Health: Helps in weight management and supports heart health. ➢ Moral Implications: People can enjoy meat-like products by choosing plant-based substitutes while avoiding the ethical quandaries linked with animal farming and slaughter. ➢ Eclectic Taste: Mimic the taste and texture of traditional meats, offering a satisfying and familiar culinary experience.	➢ Material Selection and Handling: To achieve the desired sensory experience and nutritional value, it is necessary to selectively choose and process plant-based ingredients. ➢ Market Preference and Vision: To overcome ideas or judgments about their taste, texture, sugar, refined oil, dextrose, or modified cornstarch barriers. ➢ Reliability and Cost: Enhancing production capacity and optimizing distribution networks challenge plant-based meats to be more readily available and cost-effective for consumers. ➢ Breakthrough: New advancements are required to improve the flavor, texture, and nutritional value of plant-based meats.	[89]
Insect-based meat	➢ Sustainable Efficiency: Requires less feed and resources than traditional livestock as well as produces fewer greenhouse emissions. ➢ Nutrients: Rich source of protein, healthy fats, vitamins, minerals, and fiber, also provides essential amino acids and micronutrients, which make insect-based meat a potentially healthy food option. ➢ Food Sovereignty: Improve the availability of food, particularly in areas with limited access to traditional protein sources. ➢ Dependable Source: Insects are easy to breed and grow, making them a reliable supply of protein.	➢ Commercial Acceptance: Overcoming food neophobia, as well as altering consumer perceptions and attitudes toward insect-based proteins present significant challenges. ➢ Legal Basis: Establishing clear norms and standards for the production and sale of insect-based meat that includes addressing safety concerns, labeling requirements, and ensuring compliance with food regulations. ➢ Demand for Products: The rise in insect farming to meet the demand for insect protein creates logistical challenges. ➢ Technological lead: The development of efficient and automated rearing methods is essential to ensure a steady supply.	[90]
Mycoprotein-based meat	➢ Nourishment: High-protein, fiber-rich food that contains all of the essential amino acids required for good physical condition. ➢ Cardiac Wellness: Low in fat and cholesterol, which can contribute to better heart health. ➢ Ecological Footprint: Reduction in water and land resources requires a more sustainable option as the global population continues to grow. ➢ Adipose Reduction: Prevents overeating and supports weight management. ➢ Flexibility in Diets: Provides a meat-like texture that can appeal to those who are transitioning away from animal products or who have dietary restrictions.	➢ Hypersensitivity: Potential allergen, which can lead to dangerous reactions upon consumption. ➢ Manufacturing cost: The latest mycoprotein production methods are costly, leading to prices similar to traditional meats, which limits accessibility and adoption. ➢ Public Approval: Greater public awareness of mycoprotein's health and environmental advantages is needed, as many consumers may resist switching from traditional meat due to established preferences and cultural norms. ➢ Industrial Scale Production: Expanding production challenges in terms of texture, sustainability, and consumer acceptance have to be addressed effectively using ongoing technological innovations.	[76]
Microalgae-based meat	➢ Nutritional and Health Benefits: Enhanced nutritional profile and provides bio-active compounds, potentially diminishing the reliance on synthetic fortificants and chemical preservatives. ➢ Functionality: Improves texture and flavor and act as an emulsifier and foaming agent ➢ Sustainability: Captures CO_2 and reduce the carbon footprint of food production	➢ Low cell density: High cell densities are critical for economic feasibility because many microalgae species have minimal biomass concentrations in natural conditions. ➢ Production expenditure: The construction and operating costs of photobioreactors and harvesting methods can be prohibitively expensive. ➢ Contamination: Open systems are especially sensitive to pollution, which can reduce output.	[82]

SWOT analysis

Consuming meat is a vital part of diets worldwide and is deeply intertwined with food preferences, cultural customs, and economic activity. However, because of its popularity in contemporary diets, several intricate problems have emerged, demanding a methodical examination to comprehend its effects fully. The SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis provides a methodical framework for assessing the various facets of meat consumption (Table 5). This analysis attempts to shed light

Table 5. SWOT analysis of meat and meat alternatives

Parameters	Meat	Meat alternatives	References
Strength	➢ Nutrient Dense: High concentration of protein, lipids, vitamins (B_{12}, B_6, niacin), and minerals (iron, zinc), which are required for human health. ➢ Well-being: Meat consumption contributes to lower individuals' iron deficiency anemia (IDA) with increased bioavailability when compared with other food resources. ➢ Cultural Interest: Various regional and traditional diets around the world rely heavily on meat. ➢ Economic Effects: Millions of people worldwide depend on livestock for a living, especially in rural and agricultural areas. ➢ Consumer preference: A lot of people enjoy the flavor, texture, and satisfaction that comes with eating meat.	➢ Health Plan: Meat alternatives frequently have less saturated fat and cholesterol than traditional meats, which helps minimize the risk of cardiovascular disease. ➢ Environmental Conservation: Plant-based as well as lab-grown meat alternatives offer a reduced environmental impact of carbon dioxide emissions, utilization of land, and water use than traditional meat production. ➢ Ethical Dimension: Many customers pick meat alternatives because they are concerned about animal welfare and ethical issues associated with meat consumption. ➢ Revolution Equality: Continuous advancement in plant-based and lab-grown meat technology is broadening the diversity and availability of meat substitutes, appealing to a wider range of customers.	[92]
Weakness	➢ Medical Challenges: A disproportionate amount of red and processed meats has been related to an elevated risk of cardiovascular disease, specific malignancies (colorectal cancer), and other medical issues. ➢ Environmental Implications: The meat industry causes major releases of greenhouse gases, forest loss, contamination of water, and loss of biodiversity. ➢ Substantial Resources: Maintaining livestock takes a lot of water, feed crops (which may be utilized for human consumption), as well as land. ➢ Social Issues: Consumers are becoming increasingly concerned about animal welfare and the moral implications of industrial farming practices. ➢ Health Disorders: Health disorders were linked to excessive meat eating, particularly red meat. Diseases such as bovine tuberculosis have been transmitted to humans through the consumption of infected animal flesh, disrupting biodiversity.	➢ Nutrient Profile: Certain meat replacements may lack key critical elements present in meat, especially vitamin B12, iron, and zinc, while fortification attempts are being made to address this. ➢ Production Cost: Meat substitutes can be priced higher than traditional meats owing to costs associated with manufacturing and efficiencies of scale, and this might limit access, particularly among lower-income populations. ➢ Consumer Endorsement: Creating similar taste, texture, and overall sensory experience that comes from conventional meats can be difficult, limiting consumer acceptability and adoption. ➢ Market Adoption: Concerns regarding the implementation of processed foods, chemicals, including preservatives in some meat substitutes could discourage health-conscious shoppers.	[93]
Opportunities	➢ Human Demand on Nature: The increasing need for plant-based and lab-grown meat alternatives creates an opportunity to lessen the environmental impact of meat consumption. ➢ Health Trend: Flexible eating habits and vegetarian lifestyles are becoming more popular, as people become more aware of the health benefits of plant-based diets. ➢ Technical Developments: Innovations in agriculture and food technology may result in more environmentally friendly and effective meat production systems. ➢ Regulatory Compliance: Government initiatives such as supporting ethical farming and limiting meat consumption may open up chances for innovation and market expansion in other sources of protein.	➢ Commercial Demand: The growing public interest in plant-based diets and environmentally friendly choices is driving market expansion for meat alternatives. ➢ Technological Improvements: Innovative developments based on plants and cell-based farming is enhancing taste, texture, and nutritional profile of meat alternatives. ➢ Administrative Support: Federal initiatives encouraging sustainability and nutritious eating may offer incentives and support to meat replacement companies. ➢ Regional Expansion: There are opportunities to provide meat substitutes in countries where meat consumption has traditionally been strong, appealing to health-conscious and ecologically sensitive people.	[94]
Threats	➢ Industry Resilience: Established meat industries and cultural traditions may oppose transitions to diets based on plants and alternative proteins. ➢ Economic Consequences: Decreases in meat consumption could have a significant impact on economies that rely significantly on livestock production and exports. ➢ Consumer Trends: Challenging entrenched consumer habits and preferences for animal products may present problems for alternative protein markets. ➢ Socio-economic: Sociopolitical factors, such as lobbying efforts and public perception, may influence the implementation of programs that promote sustainable diets and reduce meat consumption.	➢ Industrial Development: Traditional meat industries may reject or strongly compete with meat alternatives, potentially altering market dynamics and customer preferences. ➢ Market Demand: Addressing mistrust and influencing consumer views of the flavor, texture, and nutritional value of meat alternatives continues to be a problem. ➢ Logistics Support: Reliance on specific crops or technology for meat substitutes may bring risks such as interruptions to the supply chain, climate change effects, and market volatility. ➢ Legal Barriers: Legislation and labeling requirements for meat alternatives may differ across locations, creating compliance issues and market entrance hurdles.	[91]

on the complications surrounding meat consumption by exploring the internal strengths and weaknesses of meat consumption, besides the external opportunities and threats from societal, environmental, and economic outlook, as well as the external possibilities and dangers that it faces. The following table examines meat consumption using a SWOT analysis, highlighting existing constraints and potential opportunities within the frame of developing food production.

Conclusion

Meat was identified as a stable food source but its impacts on health and the environment are yet to be considered. The current meat production system is found associated with environmental pollution, biodiversity loss, impacts on human health, GHG emission, etc., and thus meat alternatives are found to be a promising choice for reducing conventional meat production. The meat consumption trend was associated with high GHG emission that leads to global warming, which probably makes life harder on Earth. The ever-growing demand for meat and increasing population has led to a great increase in meat consumption trend. By considering its impacts, the trend should be decreased for the sustainability of life on Earth. Meat alternatives are a better option for reducing conventional meat consumption, but their acceptability as a meat substitute is a major problem. In-vitro meat and PBMA have already acquired a position in the global market but insect-based meat alternatives remain a major issue due to the low acceptability of insects as a food source by consumers, even though insects are a good source of proteins. In-vitro meat has acquired great acceptance among consumers and it was successfully developed as food for astronauts, but its huge production based on consumer demand remains a problem. Technologies have to be developed in the future for the further launch of meat analogs in the global market. Studies on meat alternatives are still going on for increasing their production and acceptance among consumers.

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