



The Evolution of Meat Production: Historical Foundations and Contemporary Advances in Cultured and Plant-Based Alternatives

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Abstract

Artificial meat, a groundbreaking innovation in the 21st-century food industry, has drawn significant attention from researchers and industry professionals. This review explores the historical development and evolution of artificial meat, from ancient China's use of tofu to modern advancements in plant-based and cultured meat in the West. It highlights significant milestones and examines the environmental and nutritional impacts of artificial meat.

The review covers early tofu production in China, the development of textured vegetable protein (TVP) in the West, and the rise of products like the Impossible Burger and Beyond Burger. It also examines cellular agriculture and cultured meat advancements by companies such as Memphis Meats and Aleph Farms. Findings indicate that artificial meat production can enhance environmental sustainability by reducing resource consumption and greenhouse gas emissions. It provides a viable alternative to conventional meat, addressing the dietary needs of a growing global population with health benefits due to lower saturated fat and cholesterol levels and the absence of antibiotics and hormones. However, challenges such as high production costs, consumer acceptance, and regulatory hurdles persist. Continued research, innovation, and collaboration are crucial to fully harness the potential of artificial meat and ensure a sustainable food system.

Keywords: Artificial meat, food industry innovation, tofu, environmental sustainability, technological advancements, dietary needs, greenhouse gas emissions, meat alternatives.

Introduction

In recent decades, concerns about the environmental impacts of traditional meat production and the rising global demand for protein have heightened interest in artificial meat alternatives. Traditional meat production is criticized for its substantial use of natural resources, greenhouse gas emissions, and negative effects on climate change. These challenges have driven researchers and industry professionals to seek innovative solutions, with artificial meat emerging as a promising alternative [1, 2] [3].

Artificial meat includes products designed to substitute for animal meat, mimicking its taste, texture, and nutritional properties. These substitutes are typically derived from plant-based sources such as soy and peas, or produced through novel technologies like cellular agriculture, where animal cells are cultured in controlled environments to create meat-like products [4-6].

The concept of artificial meat has a long and transformative history. In ancient China, tofu, made from processed soybeans, was one of the earliest meat substitutes, dating back to the Han Dynasty (206 BCE to 220 CE). Tofu became a primary source of plant-based protein in the Chinese diet. Since then, the concept of artificial meat has evolved significantly, leading to the diverse and advanced products available today [7, 8].

Research in artificial meat is crucial, as these products can address numerous environmental and food-related challenges. With the global population increasing and the demand for protein rising, the need for sustainable and renewable resources is more critical than ever. Artificial meat offers a solution that can meet the dietary needs of a growing population while reducing pressure on natural resources and lowering greenhouse gas emissions [9, 10].

Despite its potential, the development and acceptance of artificial meat face several challenges, including high production costs, the need to improve taste and texture, and consumer acceptance. However, there are also numerous opportunities in this field. Technological advancements are gradually reducing production costs and enhancing product quality, and increasing public awareness of environmental and health issues is contributing to broader acceptance of these products [2, 11, 12].

The role of industry and researchers in the development of artificial meat is pivotal. Companies like Impossible Foods and Beyond Meat have introduced innovative products through significant investments and advanced scientific research. Researchers are continually improving production processes and product quality, driving progress in this industry. International collaborations and knowledge exchange between researchers and industry professionals can further accelerate the development and acceptance of artificial meat [13, 14].

This review article aims to provide a comprehensive overview of the history and evolution of artificial meat in different countries and analyze its impacts on the food industry and the environment. The article begins with an examination of the historical use of tofu in ancient China, followed by major advancements in the West and modern developments in new products. Finally, the discussion and conclusion will analyze the benefits and challenges of artificial meat and suggest directions for future research. This article aims to enhance awareness and understanding of the significance and potential of artificial meat.

Literature Review

Historical Background of Artificial Meat in China

The Beginnings of Tofu Production in Ancient China

The history of artificial meat in China is long and storied. Tofu, recognized today as one of the most significant meat substitutes in vegetarian diets, has its roots in ancient China. It is believed that tofu was invented during the Western Han Dynasty (206 BCE to 9 CE). Some historical sources suggest that tofu was created by Prince Liu An, the ruler of the Huainan region in Anhui province. Although these stories are often regarded as legends, the history of tofu in China is closely linked to this period. Tofu is produced through a simple process that involves soaking, grinding, boiling, and straining soybeans. The resulting soybean milk is then coagulated using mineral salts or lemon juice to form tofu curds. This process, relying on the basic agricultural and food processing techniques of ancient China, gradually improved, leading to the mass production of tofu. Tofu quickly spread throughout China and became a staple in the diet of the Chinese people. Its consumption was particularly important during times of famine and food shortages, serving as an inexpensive and nutritious protein source. During the Tang Dynasty (618-907 CE), tofu consumption peaked and was widely mentioned in the literary and historical texts of the period. In China, tofu was

not only valued as a protein source but also held cultural and religious significance. Many Buddhist monks in China used tofu as a meat substitute to adhere to their teachings on non-violence and the avoidance of killing animals. This practice led to the widespread use of tofu in Buddhist temples, making it an integral part of Chinese culinary culture. Buddhism, introduced to China during the Han Dynasty, played a significant role in promoting tofu consumption. Buddhist monks, who followed vegetarian diets, adopted tofu as a primary protein source and promoted its use among the general population. The knowledge of tofu production spread from China to other East Asian regions, including Japan and Korea. In Japan, tofu was introduced during the Nara period (710-794 CE) and quickly established itself in Japanese culinary culture. In Korea, tofu also became a fundamental component of traditional Korean cuisine and an essential element in the diet of the Korean people [15-17].

The Expansion of Tofu Consumption During the Tang Dynasty (618-907 CE)

During the Tang Dynasty, significant advancements in agriculture and food production occurred, including the development of agricultural techniques, the use of new tools, and improved irrigation systems. These transformations led to increased soybean production, the primary ingredient in tofu. The boost in soybean production, particularly in the fertile northern and central regions of China, facilitated the mass production of tofu. Due to its high nutritional value and affordability, tofu became popular among various social classes during the Tang Dynasty. It quickly gained popularity among the poor who needed inexpensive food sources. Additionally, tofu was well-received by the aristocracy and the court due to its pleasant taste and versatility in various dishes. During the Tang period, tofu was widely mentioned in the literary and historical texts of the era. Poets and writers of the Tang Dynasty referenced tofu, highlighting it as a beloved and nutritious food. For instance, the renowned poet Li Bai mentioned tofu in one of his poems, describing it as a simple yet delightful food. These references indicate the important role of tofu in the diet and culture of the Tang Dynasty [15, 18].

The Expansion of Tofu Consumption During the Song Dynasty (960-1279 CE)

During the Song Dynasty, technological advancements and production techniques improved the processes for making tofu. The development of new methods for processing soybeans and enhancing coagulation techniques made tofu production more efficient and cost-effective. These advancements facilitated the mass production of tofu and reduced production costs.

The development of trade networks and improved transportation systems made the distribution of tofu easier across China. The thriving urban markets of the Song Dynasty introduced tofu as an important commodity in the diet of the people. Tofu was widely sold in local markets and became a staple in street foods.

Tofu consumption as a daily food among the general population increased significantly during the Song period. Population growth and the need for sustainable food sources made tofu an attractive, affordable, and nutritious option. Tofu's affordability and versatility in various dishes made it a staple on Chinese tables.

The Song Dynasty saw great diversity in tofu products. Various types of tofu, including soft tofu, firm tofu, dried tofu, and fermented tofu, were produced and consumed. This diversity allowed people to use tofu in different ways in their cooking, enjoying its various flavors and textures.

Tofu became an important component of official banquets and court feasts during the Song Dynasty. Due to its pleasant taste and nutritious properties, tofu was used in official dishes and ceremonial feasts. Tofu was also widely mentioned in the literary works and art of the Song period. Song writers and poets referenced tofu, highlighting it as an important and popular food [17, 19].

Geographical and Climatic Impacts on Tofu Production

a) Climatic Conditions and Soybean Growth

Tofu production is directly linked to the cultivation of soybeans, its primary ingredient. Climatic conditions play a critical role in soybean production. Soybeans, as an agricultural crop, require moderate temperatures, sufficient rainfall, and fertile soil. Regions with warm, humid summers and cold, dry winters provide the ideal conditions for soybean cultivation. In China, the northern and northeastern regions, such as Heilongjiang and Jilin provinces, have become primary soybean production centers due to their favorable climatic conditions [20].

b) Soil and Water Resources

Nutrient-rich soils with suitable structure are essential for optimal soybean growth. Loamy soils, which have good water retention and drainage capabilities, offer the best conditions for soybean cultivation. Additionally, access to adequate water resources is crucial for soybean and subsequently tofu production. In ancient China, advanced irrigation systems such as canals and dams were developed, enabling farmers to irrigate their crops effectively even during drought periods [21].

c) Geographical Variations in Tofu Production

Geographical differences across various regions of China led to diversity in tofu production. For example, in northern China, firm tofu, which requires less moisture, was more commonly produced. Conversely, in southern regions, soft and watery tofu, which needs more humidity, was prevalent. These variations reflect the geographical influences on tofu production and consumption in different parts of China [16].

d) Climate Change and Its Impact on Tofu Production

Climate changes over different historical periods have had significant impacts on soybean and tofu production. Periods of drought and temperature fluctuations could severely affect soybean yields. For instance, during periods of reduced rainfall, soybean production would decrease, leading to tofu shortages in the market. Conversely, periods with adequate rainfall and favorable temperature conditions resulted in increased production and supply of tofu [17, 22].

e) **Agricultural Efficiency and Tofu Production**

The development of agricultural techniques and increased efficiency in soybean production had a direct impact on tofu production. The use of drought-resistant and pest-resistant seeds, chemical and organic fertilizers, and advanced agricultural techniques all contributed to increased soybean yields and, consequently, tofu production. These advancements, particularly during the Song Dynasty, which witnessed significant agricultural progress, played a crucial role in the expansion of tofu production [15].

Development of Tofu Production Technologies

a) **Traditional Methods of Tofu Production**

Initially, tofu production was carried out using traditional and manual methods. These processes involved soaking soybeans, grinding them to extract soy milk, boiling the soy milk, and finally adding coagulants to form tofu curds. These manual processes required skilled laborers who could meticulously perform the various stages of production [15].

b) **Advances in Soybean Processing**

Over time, and with technological advancements, soybean processing improved. During the Song Dynasty, more advanced techniques for grinding and boiling soybeans were employed. The use of stone mills instead of primitive manual tools increased the efficiency of soy milk production. Additionally, the use of larger and more durable pots for boiling soy milk allowed for the production of larger quantities of tofu [16].

c) **Improvement of Coagulants**

One of the most significant advancements in tofu production was the improvement of coagulants. Initially, natural substances like mineral salts were used. With the advancement of chemistry, more efficient synthetic coagulants such as calcium sulfate (food-grade gypsum) and magnesium chloride (nigari) were introduced. These materials not only had higher efficiency but also provided better quality and texture to the tofu [23].

d) **Mechanization of Tofu Production**

In modern times, tofu production has moved towards mechanization. Automated and semi-automated machines for various stages of tofu production have been introduced. These machines include electric grinders, automatic boiling pots, and molding and compression devices. These technologies not only increased production speed but also improved health standards and product quality [24].

e) **Optimization of Production Processes**

Optimizing tofu production processes using modern technologies has also been crucial. These optimizations include precise control of temperature and time during various production stages, the use of advanced filters to remove impurities and improve soy milk quality, and the use of more advanced techniques for shaping and compressing tofu [25].

f) **Advances in Packaging Technologies**

The development of packaging technologies has also played a significant role in the tofu industry. The use of sterilized packaging and natural preservatives has extended tofu's shelf life. These innovations have been particularly effective in increasing tofu exports and providing greater accessibility to this product in remote areas [26].

g) **Diversification of Tofu Flavors and Textures**

New technologies have enabled the production of tofu with a variety of flavors and textures. Adding various ingredients like spices, herbs, and natural flavorings has led to the production of different types of tofu with diverse tastes and textures. These innovations have helped attract more consumers and increase the popularity of tofu [22, 27].

Introduction of Tofu to Japan and Other Asian Countries

a) **Introduction of Tofu to Japan**

The introduction of tofu to Japan dates back to the 8th century during the Nara period (710-794 AD). This food product was introduced to Japan by Buddhist monks who traveled to China for study and religious missions. Buddhists adopted tofu as a protein substitute in their diet due to the prohibition of meat consumption in Buddhism. Japanese monks, upon returning to their country, brought back tofu production techniques and gradually popularized it in temples and subsequently in Japanese society.

During the Heian period (794-1185 AD), tofu consumption in Japan expanded and became a staple in the diet. In this period, tofu gained popularity not only in temples but also in households and local markets. The variety of preparation and serving methods in Japan led to the creation of different types of tofu, including abura-dofu (fried tofu) and zaru-dofu (drained tofu). In the Edo period (1603-1868 AD), tofu became a permanent fixture in Japanese culinary culture. Tofu production and sales evolved into a thriving industry, making tofu an affordable and nutritious food accessible

to all social classes. This product played an important role in traditional Japanese dishes such as miso soup and natto (fermented soybeans), becoming a mainstay in Japanese cuisine [15, 28].

b) Introduction of Tofu to Korea

Tofu was introduced to Korea from China in ancient times. Koreans quickly embraced this food and adopted tofu production techniques. In South Korea, tofu became an essential part of the diet, and various types of tofu, such as dubu (soft tofu) and baekdubu (white tofu), were produced [29].

c) Introduction of Tofu to Vietnam and Thailand

Tofu was also introduced to Vietnam and Thailand through trade and cultural exchanges. In Vietnam, tofu became a popular ingredient in local dishes like pho (noodle soup) and bánh khọt (small pancakes). In Thailand, tofu played a significant role in Thai dishes such as pad thai and massaman curry, gaining rapid popularity due to its high nutritional value and affordable price [30].

d) Cultural and Culinary Impacts of Tofu in Asia

The introduction of tofu to various Asian countries had significant cultural and culinary impacts. Each country, based on its traditions and culinary culture, developed unique methods for preparing and serving tofu. This diversity and variety in tofu consumption not only enriched the culinary culture of Asia but also played a crucial role in improving food security and nutrition for the people in these regions [24, 31].

Innovations and Varieties of Tofu in China

a) Introduction to Different Types of Tofu

In China, tofu is categorized into various types, each differing in production methods, texture, and flavor. This diversity not only reflects China's rich culinary culture but also meets the diverse nutritional needs and preferences of the population.

b) Soft Tofu (嫩豆腐, Nèn Dòufu)

Soft tofu is one of the most popular types of tofu, known for its delicate and smooth texture. It is commonly used in soups, stews, and steamed dishes. Due to its high water content, soft tofu cooks faster than other types and absorbs the flavors of other ingredients well.

c) Firm Tofu (老豆腐, Lǎo Dòufu)

Firm tofu has a denser and less watery texture compared to soft tofu. It is typically used in fried, grilled, and stewed dishes. Due to its firmer texture, it holds its shape better during cooking and is less likely to crumble, making it suitable for a variety of culinary applications.

d) Smoked Tofu (熏豆腐, Xūn Dòufu)

Smoked tofu is a unique innovation in tofu production. After the initial production, this type of tofu is exposed to smoke from specific types of wood, imparting a distinctive flavor and pleasant aroma. Smoked tofu is often consumed as a snack or used in grilled dishes, and it enjoys considerable popularity due to its unique taste.

e) Fermented Tofu (臭豆腐, Chòu Dòufu)

Fermented tofu, or "stinky tofu," is a distinct type of tofu known for its strong flavor and odor resulting from the fermentation process. It is commonly sold as street food and consumed as a snack. The fermentation process endows stinky tofu with special nutritional properties, making it a rich source of probiotics.

f) Egg Tofu (鸡蛋豆腐, Jīdàn Dòufu)

Egg tofu is a combination of eggs and soy milk, known for its soft texture and mild flavor. It is a popular alternative to regular tofu, especially in steamed dishes and soups. Due to its high protein content, egg tofu is highly nutritious.

g) Modern Innovations in Tofu Production

With advancements in technology and market demand, numerous innovations have emerged in tofu production. One such innovation is the production of organic and non-GMO tofu, which has gained popularity due to health and environmental concerns. Additionally, the production of ready-to-eat tofu and tofu snacks represents another significant development in this industry.

h) Vegetarian Tofu (素豆腐, Sù Dòufu)

Vegetarian tofu is another interesting innovation in the tofu industry, specifically designed for vegetarians and vegans. This type of tofu is produced without any animal-derived ingredients and is typically flavored with natural additives such as vegetables and spices.

i) Fortified Tofu (强化豆腐, Qiánguà Dòufu)

Fortified tofu is produced by adding extra nutrients such as vitamins and minerals. This type of tofu is considered a more complete nutritional source and is especially recommended for specific population groups, such as children and the elderly.

j) Flavored Tofu (风味豆腐, Fēngwèi Dòufu)

Flavored tofu is produced by adding various seasonings such as garlic, onion, ginger, and other spices. Due to its unique taste, this type of tofu is used in a variety of dishes, such as salads and stir-fries, and helps attract consumers.

k) Frozen Tofu (冻豆腐, Dòng Dòufu)

Frozen tofu is a modern method of preserving tofu, which increases its shelf life and retains its nutritional value. This type of tofu is typically used in soups and stews and develops a unique texture after thawing, distinguishing it from other types of tofu.

l) Impact of Innovations on the Tofu Market

The numerous innovations in tofu production have led to increased demand and expansion of the tofu market. The production of diverse types of tofu with varying flavors and textures has helped attract new consumers and increase the popularity of this food product. These innovations have also contributed to increased exports and the introduction of tofu to global markets [15, 16, 24, 25, 27].

Developments in the West in Cultured Meat Production

Introduction and Significance of Cultured Meat Production

Cultured meat, also known as lab-grown meat, is an innovative solution aimed at reducing dependency on industrial livestock farming and mitigating the environmental impacts of meat production. This approach not only helps in reducing greenhouse gas emissions but also conserves natural resources by lowering the need for agricultural land and water.

The serious pursuit of cultured meat production in the West began in the early 2000s. The first prototype of cultured meat was produced in 2013 by a research team led by Mark Post at Maastricht University in the Netherlands. This lab-grown hamburger, made from cow muscle cells, was unveiled at a public event in London [32, 33].

Extensive research has been conducted to improve the cultured meat production process. These studies encompass the development of new methods to enhance production efficiency, reduce costs, and improve the final product's quality. Some of the most significant advancements in this field include:

- Use of Stem Cells: Employing stem cells can lead to the production of larger quantities of high-quality muscle tissue.
- Development of Optimized Culture Media: Culture media, which contain the essential nutrients for cell growth, play a crucial role in increasing the yield of cultured meat.
- Bioreactors: The use of advanced bioreactors for cultured meat production helps in scaling up production and reducing costs [34].

In recent years, several companies in the West have ventured into cultured meat production. Some of the leading companies in this field include:

- Memphis Meats: Founded in 2015, this American company specializes in producing cultured beef, chicken, and duck [35].
- Mosa Meat: A Dutch company founded by Mark Post, focusing on producing lab-grown hamburgers [33].
- Just (formerly Hampton Creek): Known for its innovative food products, including cultured meat and plant-based eggs.

Recently, new and diverse products have entered the market. Some of these products include:

- Cultured Hamburgers: Lab-grown hamburgers made from cow cells that taste similar to traditional burgers.
- Cultured Chicken and Fish: Development of cultured meat from chicken and fish cells, which are promoted as healthier and more sustainable alternatives.
- Hybrid Meats: Combining cultured meat with plant proteins to produce food products with high nutritional value and better taste.

Cultured meat production faces several challenges. Some of these challenges include:

- High Costs: The cost of producing cultured meat is still high, necessitating further research to reduce expenses.
- Consumer Acceptance: Public acceptance of cultured meat as a legitimate food option requires more effort in education and marketing.
- Regulations and Standards: Developing the necessary regulations and standards for the production and sale of cultured meat is also a significant issue that needs to be addressed.

One of the primary advantages of cultured meat is its potential to reduce the environmental impact of meat production. Cultured meat can significantly lower greenhouse gas emissions, water consumption, and conserve natural resources. Studies have shown that cultured meat production can lead to a reduction of up to 96% in greenhouse gas emissions and a 99% reduction in water use [1, 11].

Recent studies on cultured meat highlight significant advancements. Some of these studies include:

- Studer et al. (2021): This study examined the environmental and economic impacts of cultured meat production, indicating that it can lead to substantial reductions in resource consumption [36].

- Post et al. (2020): This study explored new technologies in cultured meat production, showing that the use of advanced bioreactors can enhance production efficiency and reduce costs [37].

The future of cultured meat appears very promising due to its environmental benefits and potential for cost reduction. With technological advancements and increasing demand for sustainable and healthy foods, it is expected that cultured meat will become a significant component of the global food industry. Additionally, substantial investments from food companies and governmental support could accelerate this trend [38, 39].

Modern Developments and New Products

Introduction and Importance of Cultured Meat Production

Cultured meat, or lab-grown meat, represents an innovative solution aimed at reducing dependence on industrial livestock farming and mitigating the environmental impacts of meat production. This approach not only aids in reducing greenhouse gas emissions but also conserves natural resources by decreasing the need for agricultural land and water.

Serious efforts towards cultured meat production in the West began in the early 2000s. The first prototype of cultured meat was produced in 2013 by a research team led by Mark Post at Maastricht University in the Netherlands. This lab-grown hamburger, made from cow muscle cells, was unveiled at a public event in London [33].

Extensive research has been conducted to enhance the cultured meat production process. These studies include developing new methods to increase production efficiency, reduce costs, and improve the final product's quality. Key advancements in this field include:

- Use of Stem Cells: Employing stem cells can lead to the production of larger quantities of high-quality muscle tissue.
- Development of Optimized Culture Media: Culture media, which contain the essential nutrients for cell growth, play a crucial role in increasing the yield of cultured meat.
- Bioreactors: The use of advanced bioreactors for cultured meat production helps in scaling up production and reducing costs.

Several companies in the West have ventured into cultured meat production in recent years. Leading companies include [38]:

- Memphis Meats: Founded in 2015, this American company specializes in producing cultured beef, chicken, and duck [40].
- Mosa Meat: A Dutch company founded by Mark Post, focusing on producing lab-grown hamburgers [33].
- Just (formerly Hampton Creek): Known for its innovative food products, including cultured meat and plant-based eggs [41].

Modern Developments and New Products

In recent years, the development of meat alternatives has peaked with the introduction of innovative products such as the Impossible Burger and Beyond Meat [42]. Impossible Foods [43] launched a burger in July 2016 that claims to offer the appearance, taste, and cooking properties similar to beef. This product was introduced by Burger King in April 2019 as the Impossible Whopper and became one of the restaurant's most successful products. Reports indicate that the sale of this product increased customer visits by 17% in some locations, demonstrating high demand for plant-based meat products [44].

Beyond Meat has also garnered significant attention with a variety of products including Beyond Burger, Beyond Sausage, and Beyond Beef. The company experienced one of the most successful initial public offerings (IPO) of 2019, reflecting investors' confidence in the future of plant-based meat products.

By October 2019, restaurant chains such as Carl's Jr, Hardee's, A&W, Dunkin' Donuts, and KFC began selling plant-based meat products. These products quickly gained consumer acceptance, indicating growing demand for sustainable and meat-free foods. For instance, KFC introduced Beyond Fried Chicken in select U.S. locations and sold out within five hours [45, 46].

Kellogg's MorningStar Farms launched its plant protein product line, Incogmeato, in early September 2019, with plans for a nationwide release in early 2020. These products, including plant-based burgers, nuggets, and sausages, were introduced as alternatives to traditional meat products. MorningStar Farms emphasized similar quality and taste to meat products, capturing a significant market share.

These developments reflect a shift in consumer and industry attitudes towards more sustainable and healthier products. Research shows that producing plant-based meat significantly reduces water and energy consumption and has fewer negative environmental impacts. For example, producing an Impossible Burger requires 87% less water, 96% less land, and generates 89% fewer greenhouse gases compared to a beef burger.

Additionally, plant-based meat products contribute to improved public health. Studies have shown that high consumption of red and processed meat is associated with an increased risk of heart disease, type 2 diabetes, and certain cancers. In contrast, plant-based products typically contain more fiber, less saturated fat, and no cholesterol, which can help reduce these health risks [47].

Economically, the rapid growth of the plant-based meat market has created new job opportunities and increased investment in research and development. Many major food companies and restaurant chains are collaborating with plant-based meat producers to bring new and innovative products to market. For instance, McDonald's announced its collaboration with Beyond Meat in 2021 to offer the McPlant.

Ultimately, these changes in the food industry signify transformations that can help preserve natural resources, reduce greenhouse gas emissions, and improve public health. With increased consumer awareness and access to diverse plant-based products, demand for these products is expected to continue rising [48-50].

Discussion

The historical analysis of cultured meat development reveals a long and transformative journey, from the initial experiments in ancient China to the advanced modern products we see today. This history underscores humanity's ongoing efforts to find alternative solutions for protein supply, especially in the face of natural resource limitations and a growing global population. The historical developments highlight the continuous innovations and scientific and technological advancements that have gradually improved the quality and acceptance of these products.

Given the environmental challenges and global food demands, the development of cultured meat alternatives can play a crucial role in sustainable protein provision. Cultured meat production requires fewer natural resources and can help reduce water consumption, land use, and greenhouse gas emissions. These advantages, coupled with the need to feed a growing global population, underscore the importance of developing and broadly accepting these products [34].

Recent advancements in production technologies and product quality improvements indicate increasing demand and broader acceptance of these products in the market. Technologies such as plant-based burgers produced by companies like Impossible Foods and Beyond Meat have provided consumers with experiences similar to traditional meat consumption. These advancements suggest that despite challenges such as consumer acceptance and production costs, the future of cultured meat alternatives looks promising. Companies and researchers are working on reducing production costs and scaling up these products, potentially leading to greater accessibility and more affordable prices for consumers [44, 51].

Conclusion

Ultimately, studies show that cultured meat alternatives can reduce negative environmental impacts, improve public health, and meet global food needs. Numerous studies have demonstrated that consuming cultured meat can decrease the risk of diseases associated with the consumption of red and processed meats. Additionally, reducing reliance on industrial livestock farming can help preserve biodiversity and reduce the destruction of natural habitats. Given these benefits and advancements, cultured meat alternatives are positioned as key solutions to future food supply challenges and environmental sustainability. Government support, private investment, and increased consumer awareness can play significant roles in accelerating the development and acceptance of these products in global markets. Therefore, it can be concluded that with ongoing research and innovation in this field, cultured meat alternatives can significantly contribute to building a more sustainable and healthier future for all.

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