# A Comprehensive Outlook on Cultured Meat and Conventional Meat Production

Arzu PEKER[1,a], Şükrü ORKAN[1,2,b], Yılmaz ARAL[1,c], Güzin İPLİKÇİOĞLU ARAL[3,d,✉]

[1]Ankara University, Faculty of Veterinary Medicine, Department of Animal Health Economics and Management, Ankara, Türkiye; [2]Ankara University, Graduate School of Health Sciences, Department of Animal Health Economics and Management, Ankara, Türkiye; [3]Ankara University, Faculty of Veterinary Medicine, Department of Food Hygiene and Technology, Ankara, Türkiye

[a]ORCID: 0000-0002-5509-2171; [b]ORCID: 0009-0008-5452-9432; [c]ORCID: 0000-0002-1580-3100; [d]ORCID: 0000-0001-6897-8222

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✉**Corresponding author**
iplikcioglu@veterinary.ankara.edu.tr

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## Abstract

Proponents present cultured meat as a viable alternative to traditional animal-based meat production to meet the increasing demands of the growing population. This review aims to compare this subject across various dimensions, such as resource requirements, nutritional aspects, cost structure, consumer acceptance, and market trends, by focusing on recent publications. Cultured meat can be produced by applying existing cell culture practices and bio-manufacturing methods to produce tissue or dietary proteins suitable for human consumption. Studies have shown that cultured meat has some advantages over conventional meat in issues such as the environment and animal meat-related diseases. Cultured meat is a promising but early-stage technology with significant technical challenges in terms of production costs and optimized methodology. Cultured meat cannot completely achieve the texture, taste, and nutritional values of conventional meat. Religious beliefs, price, ethical values, and regional factors are important considerations in consumers' perceptions of cultured meat. Currently, the level of research conducted on aspects such as consumer acceptance, cost, texture, taste, and other characteristics closely resembling conventional meat will directly influence its entry into the market, its success in the market, and its acceptance by consumers. There is a need for further research and analysis with the joint participation of academic and sectoral stakeholders to address all technical, social, and economic dimensions.

## Introduction

The world population is currently over 8 billion, and the United Nations states that this number will exceed 9 billion by 2050. With population growth, the world's need for food will increase. By 2050, the world will need 70% more food to meet demand due to limited resources and arable land problems. By 2030, experts anticipate the annual worldwide meat production to reach 465 million tons (81). Every year, the world raises and slaughters almost 70 billion animals to meet the growing demand for meat (26).

In the conventional meat production system, new alternatives for meat have been developed for many reasons, such as public health, animal welfare, and negative environmental effects. Cultured meat is obtained from tissues and cells in a laboratory. It is also known for concepts such as cultured meat, in-vitro meat, lab-grown meat, synthetic meat, clean meat, and cell meat. Mark Post made a hamburger with cultured meat for the first time in 2013. After this event, interest in cultured meat, investments, and research on this subject increased considerably. A report estimated the cultured meat market to be valued at $1.64 million in 2021, with a projected compound annual growth of 95.8% from 2022 to 2030 (4). In another report it is stated that the cultured meat market will reach 1.66 billion dollars in 2031 and 11.13 billion dollars in 2041 (25).

Cultured meat is a promising technology, but it is still in its infancy, and its industrial production faces many obstacles (19). Consumer perception, the nutritional structure of meat, and excess production costs are some of these difficulties. According to research, the three most important factors in consumer perception of cultured meat are price, texture, and taste (18).

The following are important points for the proper development of the cultured meat industry: i) to learn more about cultured meat and to expand the technology as much as possible; ii) to improve product quality; iii) to reduce production costs; iv) to ensure product safety; and v) to improve regulatory systems and provide good market access (57).

## What is cultured meat?

There has been a tendency towards cultured meat due to the effects of conventional livestock farming on the environment, the attitudes of some people towards animal slaughter, future population growth, and the need for food. Producing cultured meat eliminates the need to slaughter animals (65). Harvest mature muscle cells cultured from myo-satellite cells on a substrate in a liquid medium under mechanical stimulation as the basic methodology (82). It was originally referred to as in vitro, but in 2011, the term "cultured meat" gained popularity due to culturing techniques. In 2015, it was called "clean meat," and this attracted more attention from consumers (14). Although many different definitions, such as "lab-grown meat," "cell-based meat," "in vitro meat," and "clean meat," are used for cultured meat, the production methods are largely the same. This method of meat production is quite different from conventional animal husbandry and is advocated by some circles, such as politicians and scientists. Today, there are many companies working to produce cultured meat products and sell them in the near future (73).

Cultured meat can be a technological, economic, and cultural revolution and has significant future potential. It creates a solution to the negative impact of conventional livestock farming on natural resources such as air, water, and soil (63). It also significantly reduces animal food-borne diseases (29). Cultured meat production under sterile conditions significantly reduces the risk of contamination (73).

## Production Methods for Cultured Meat

When producing cultured meat, the main goal is to reconstruct the complex structure of the animal musculature using a small number of cells. Cultured meat production generally consists of 5 stages: collecting a cell or tissue sample from a living animal, cell-banking, growth, harvest, and food processing (33).

Researchers take a biopsy from a live animal. Stem cells, which have the ability to multiply by cutting this muscle part but can also transform into different cell types such as muscle cells and fat cells, are released (65). Studies have reportedly shown that fetal bovine serum (FBS) is the ideal choice for a culture medium because it can support the growth of over a trillion cells, which naturally merge to create myotubes (6). However, this is not acceptable for vegans and vegetarians. To accelerate lab-grown meat production, researchers maintain the cells in a controlled environment that replicates the temperature found within an animal's body, like that of a cow (6).

Researchers use tissue and cell culture techniques to produce cultured meat. 3D printing and nanotechnology can also produce cultured meat in later stages. However, large-scale production of cultured meat requires technological advances in areas such as tissue engineering and bioreactors (78).

Embryonic stem cells and induced pluripotent stem cells (iPSCs) are required for ***the cell*** culture method. This method involves the isolation and cultivation of stem cells and adipocytes. Attached to a carrier or scaffold, these stem cells differentiate into more differentiated myotubes to form myofibers (45). One can gather, prepare, cook, and eat the resulting myofibers as ground meat or emulsified products (10). In essence, stem cells mimic the in vitro maturation phases of muscle fibers. Collagen, a naturally occurring and edible polymeric biomaterial, was used in the development of the scaffold, which enables the intricate structuring of cultured meat through 3D tissue culture (42, 54). Mechanical stretching of the scaffold aids in supplying nutrients to developing muscle cells (20). Thus, cell culture production aids in the development of tender, boneless meat (9).

Researchers first used the tissue culture technique to produce goldfish meat in vitro (7). The culture medium replicated the in vivo environment, making the cultured tissues resemble fresh fish fillets. However, the inability to precisely replicate the in vivo environment as well as the scarcity of blood and nutrients caused the growing cells to eventually turn necrotic. Various tissue culture and tissue engineering techniques proposed solutions in the following years (100).

Compared to other approaches, 3D printing is a novel and more advanced tissue engineering process. In addition to imitating the cellular structure of the muscles with 3D printers, it will also provide appropriate vascularization to carry blood to the whole organ (9). There are numerous types of 3D printers, including extrusion, inkjet, and laser-assisted bioprinters. While inkjets are the cheapest, laser-assisted ones have the highest resolution and are the most expensive. Microextrusion printers are slow and inexpensive (11).

The goal of nanotechnology, which is still in its early stages of development, is to create, test, and change materials with novel properties at the nanoscale (100 nm in diameter) (85). The ability to produce cultured meat using nanotechnology is critical for in vitro meat production, since these tiny molecules can improve the meat's color, flavor, and texture (94). In order to increase

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the performance of biomaterials in various meat products, nanomaterials such as Poly lactic-co-glycolic acid (PLGA) nanoparticles, biopolymeric chitosan nanoparticles, and capsicum oleoresin nanoparticles have been employed (68).

Naturally occurring meat nanofibers affect the texture and color of the meat after cooking. Consequently, using nanotechnology to produce cultured meat may be successful. In addition, the packaging of meat products makes considerable use of nanotechnology (78). Manufacturers use a packaging film that distributes nanoclays over a polyamide-6 (PA6) matrix to package meat products. The hardness of meat products is increased, and the $O_2$ barrier qualities are improved with this nanoclay packaging film (61). Furthermore, meat science and technology may benefit from nanoscience interventions in areas such as increased sensory acceptance, improved nutrient bioavailability, targeted delivery of bioactive substances, and improved antimicrobial effects of preservatives (78).

## Resource Requirements

The traditional livestock production system has a significant impact on the environment in terms of gas emissions, land, water, and greenhouse energy use. The impact of livestock on the emission of the three most important greenhouse gases, which are $CO_2$, $CH_4$, and $N_2O$, is 9%, 39%, and 65%, respectively. 15–24% of global greenhouse gas emissions are traced back to the global livestock production system, according to data from 2021. A huge portion of this percentage is caused by deforestation to create grazing land for livestock; however, livestock contributions to greenhouse gas emissions vary across nations and continents, as is evident (81).

The meat production system needs 15.500 $m^3$/ton of water, while the chicken production system requires 3.918 m3/ton of water to function (41), which increases the stress on water resources and the environment. In contrast with conventionally produced beef, lamb, pork, and chicken, cultured meat production emits significantly less greenhouse gas and uses less land, water, and energy by 78–96%, 99%, 82–96%, and 7–45%, respectively (89).

***Land Usage*:** Compared to conventional meat production, cultured meat causes 99% less land use (89). But there are also opposing views on this. As a source of conventional livestock manure, organic matter, nitrogen, and phosphorus, it contributes significantly to maintaining the carbon content and fertility of the soil. Livestock feed production requires 2.5 billion hectares of land, roughly 50% of the world's agricultural area; however, 1.3 billion of these hectares are pastures unsuitable for agriculture, benefiting only livestock (55). It may not be accurate to compare cultured meat to conventional meat based on land use. This comparison excludes the variety of environmental services and the effects of livestock farming methods, such as greenhouse gas (GHG) release, water use, plant and animal biodiversity (74).

***Greenhouse Gas:*** The share of carbon dioxide and nitrous oxide emissions, particularly methane, originating from ruminants' digestive tracts is quite large in world greenhouse gas emissions. While some of the studies conducted on this subject showed that cultured meat was advantageous (89), others were inconclusive (53). Fossil energy used to heat the culture cells in cultured meat production releases carbon dioxide (20). Some studies indicate that cultured meat production will have less impact on global warming in the first stage compared to conventional farming, but this will not happen in the long term. Because carbon dioxide accumulates in the atmosphere for a longer time than methane (50).

***Water Usage:*** In some studies, if we compare cultured meat with conventional meat in terms of water consumption, it is seen that cultured meat consumes 82–96% less water (89). However, although it is said that 15,000 liters of water are used to produce 1 kg of beef, 95% of this amount consists of water used to grow plant products and plants to be used in animal feeding. And in fact, it is widely accepted that 550–700 liters of water are needed to produce 1 kg of beef (27). The quality of the water used by firms that produce cultured meat is another issue. This is because chemical compounds in the water may have leaked into the environment. However, this may not occur if the situation is highly controlled (20).

## Nutritional Aspects

Conventional meat consists of a number of different parts, including muscle, fatty tissue, connective tissue, and bones. Meat is a good source of critical nutrients and bioactive compounds such as vitamin $B_{12}$ and heme iron, as well as protein, amino acids, fatty acids, minerals, and vitamins including Zn, Se, K, Na, Mg, creatine, and vitamins (A, B-complex, and D) (86, 99). In meat, the typical protein content is around 22%. Meat's amino acid composition varies depending on the animal; for instance, beef has more of the important amino acids valine, lysine, and leucine than lamb and pork (1). Additionally, a number of variables, including age, the presence of connective tissue, etc., have an impact on the amino acid and protein content of meat. The age of the animal and the amount of connective tissue are both inversely correlated with the amino acid and protein content of the meat. According to research, meat's nutritional value decreases when meat's concentrations of valine, isoleucine, phenylalanine, arginine, and methionine rise with animal age while falling with an increase in connective tissue (24).

Beef also has unsaturated fatty acids like oleic, linoleic, and arachidonic acids (1). The most beneficial and important component of beef is polyunsaturated fatty acid, also known as omega-3 fatty acid. Saturated fatty acids further significantly increase the nutritional value of beef, while extreme consumption can lead to cardiovascular diseases (CVD) (23). Minerals such as Fe, Zn, Se, K, Na, and Mg, in addition to vitamins A and B complex, are related to the nutritional value of meat. Meat is the sole source of heme and vitamin $B_{12}$. Thus, iron and vitamin $B_{12}$ make up the majority of meat's nutritional value. Specific types of gut-colonizing bacteria produce vitamin $B_{12}$, making it exclusive to animal products, while iron in meat exists as $Fe_2$, a highly accessible form of heme (23).

Cultured meat could not accurately replicate many characteristics of conventional meat, including protein content, amino acid structure, protein digestibility, fat content, vitamin-mineral content, texture, and color. More studies should be done on cultured meat in order to make cultured meat similar to conventional meat and thus create a positive perception of customer preference and ensure market entry and success. The following section focuses on the nutritional analysis of cultured meat.

***Protein, Vitamin, and Mineral:*** More research is required since there is a lack of knowledge about the factors impacting cultured meat's protein concentration, amino acid composition, and protein digestibility (59). However, morphological findings indicate that the present culturing procedures produce in vitro meat with the majority of cytoskeletal proteins in the same range as conventional meat. Although the protein content of in vitro meat has not yet been established (64, 102), Two methods to promote or monitor the synthesis of sarcomeric proteins include electrical stimulation and scaffolding that can keep the muscle fibers under tension; however, they are pricy, inefficient, and only partially scalable (102). Changing the lipid composition of the medium can control the ratio of saturated and polyunsaturated fatty acids in cultured meat, although one should consider potential effects on rancidity (10, 20). The media may need to supplement with vitamins such as vitamin $B_{12}$ and minerals such as iron, zinc, and selenium since cultured muscle cells cannot produce them. In order for these vitamins and minerals to enter the cells, there must be transport systems and binding proteins in the medium (66, 102). Genetically altered animal cells can enhance the nutritional profile of the meat produced. For instance, Stout et al. (83) demonstrated how to create prokaryotic enzymes in primary bovine and immortalized murine muscle cells to synthesize synthetic carotenoids (phytoene, lycopene, and carotene). It remains unclear how these chemicals absorb into cultured meat (32, 83). Beyond the vitamins and minerals included in cultured meat, it is unclear whether any supplements given by the growing medium will also benefit human health (20).

***Textural aspects:*** More fundamental research is required to assess the impact of embryonic or neonatal isoforms of actin and myosin on potential protein deterioration during or after cell harvesting. Therefore, it is difficult to predict how the texture will change, as well as the rate and scope of the tenderization process (32, 102). Cultured meat can produce steaks and whole slices of meat. Processed meats like ready-made sausage and hamburger patties can also be made using cultured meat. The first option is the most challenging due to the thickness of the desired result, the lack of blood, the limitations on oxygen and nutrient delivery over the entire structure during differentiation, and the difficulties in generating the characteristic texture of conventional meat. Thin sheets of cultured cells measuring a few hundred microns, which have already been successfully generated, can be used for the latter. Electrical and/or mechanical stimulation can increase the size and length of immature myofibers, enhancing their structure and leading them to resemble more mature muscle fibers by creating more mature myofibrillar proteins (32). It is still unknown how well these processes work at producing myofibers that can take on the role of the meat proteins found in fresh and processed meats (32).

***Taste and Odor Properties:*** It is one of the most difficult stages to compare the taste of cultured meat with conventional meat because meat consists of many components (18). In addition to the Maillard reaction products that occur when conventional meat is heated, the breakdown of lipids, peptides, and amino acids and the interactions between these molecules also have an impact on meat odor (84). Flavor precursors occur postmortem in conventional meat, so it is unknown how these characteristics will manifest in cultured meat (32). In addition, the lack of adipocytes in growing muscle fibers in vitro may limit the sensory qualities of the cultured meat produced (40, 43). Fat has an important role in the aroma, juiciness, and tenderness of meat, and various methods have been reported to improve this condition in cultured meat. Co-growth of myoblasts and preadipocytes can increase the ratio of intramuscular fat (73). Carotenoids reduce lipid oxidation and by adding carotenoids to cultured meat, sensory properties and shelf life can be increased (83). At the product manufacturing step, fat and flavoring agents can be added to the cultured meat, taking client preferences into account (32, 102). Techniques such as heating mushroom protein hydrolysates or combining defatted soybeans with soy sauce hydrolysates can make cultured meat smell like traditional meat (101).

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***Color Properties:*** Cultured meat is colorless because it contains very little myoglobin. One can alter the color of cultured meat to resemble that of normal meat by directly incorporating myoglobin or hemoglobin into the medium or by adding ingredients like beetroot juice or saffron (though these may impact the flavor) (43, 77). Metmyoglobin and hemoglobin were added to the culture medium in one study, and as a result, it was found that culture meat grown in the medium with the additional metmyoglobin had a hue that resembled beef when cooked (77). To increase the color properties of cultured meat, hemoglobin can be acquired by extracting it from animal blood, plant tissue, or by synthesizing it utilizing microbial cells. However, these procedures require a lot of time and labor, or they are unsuitable for scaling up when biosynthesis is involved (101). However, GMOs can boost microbial production (13). European Food Safety Authority (EFSA) received a dossier for an application to produce soy hemoglobin in 2019. However, compared to animal hemoglobin, soybean hemoglobin is distinct in terms of both structure and function. The use of food-grade microbial strains and properly purified hemoglobin requires special attention (101).

## Economic Impact

It is very important to examine cultured meat from an economic perspective. The cost of cultured meat may have an impact on inequality, and it is believed that traditional breeders and enterprises that provide animal food may suffer as a result (12, 82).

***Agricultural Employment:*** Although people working in the agricultural sector in the EU account for only 4.4% of total employment (30), this rate is much higher in less developed countries (72). Cultured meat may eventually replace conventional meat (97). New employment opportunities will arise with cultured meat, but people engaged in agriculture generally have lower education levels (30) and, due to the technical nature of cultured meat production, highly educated people are required to work in this sector. Therefore, people engaged in traditional animal husbandry may lose their jobs to a great extent. However, traditional producers can provide limited and high-quality service in the meat market (12). They may adopt agroecology concepts or use biotechnologies such as cloning, genetic modification, etc. to improve sustainability. Alternatively, they can produce products such as biofuel, etc., for human consumption (47).

***Consumer Inequality:*** Some researchers on cultured meat are concerned that inequality between the poor and the rich may increase further (22, 12, 82). They proposed an alternative perspective, indicating that while the affluent may prefer conventional meat, cultured meat could be more appealing to the underprivileged (12). In contrast, Cole and Morgan (22) thought that rich people could consume cultured meat, but poor people would still have to kill animals to consume meat. Although cultured meat's cost has drastically dropped recently, experts anticipate its initial market price to exceed that of conventional beef (36). Purdy (67) suggests that in the initial phase, restaurants may only be able to sell cultured meat at high prices. According to Fountain (31), in the later stages, the price of cultured meat may decrease much more and be sold cheaper than conventional meat. Furthermore, if the cost of cultured meat falls below that of conventional meat, the meat industry may reach a turning point (15).

***Economic Impacts on Developing Countries:*** Agriculture and animal husbandry play an important role in low-income countries such as South Asia and some African countries. The livestock sector accounts for approximately 40% of global agricultural gross domestic product (GDP) and approximately 30% of agricultural GDP in the developing world (98). 1.3 billion poor people in the world live in developing countries and depend on livestock for their livelihood (69). Livestock farming is a very important sector in these countries, as it can meet food, income, and employment needs. Livestock farming acts as a buffer to reduce the impact of instability in crop production on maintaining the availability of food produced for human consumption and thus maintaining a stable food supply (58). Livestock farming serves as an insurance policy or bank account in many developing countries (60). As a result, cultured meat may negatively affect the livestock industry, especially in developing countries. In these countries, cultured meat will have an impact on both exports and employment. Although cultured meat does not necessarily indicate animal production elimination, it will affect the sustainability of livestock farming. Furthermore, due to cultured meat production, exports of conventional meat to developed countries may decrease significantly, causing some economic problems (43).

***Cost Structure:*** The price is probably the most important consideration when purchasing cultured meat. Although the cost of cultured meat decreases in later stages compared to the first cultured hamburger patty, it is still more expensive than conventional meat. In addition, since the technologies used to produce cultured meat change every day, it becomes difficult to calculate the cost. Garrison et al. (34) calculated the cost of large-scale cultured meat production. The goal of their study was to determine how much it would cost to produce in vitro meat in a large-scale production facility that produces 540,000 kg of product per year. In this study, in addition to basic costs such as culture media, bioreactors, and labor (these

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three elements account for 80% of the total cost), costs such as employment and transportation were also calculated in detail. The expected production cost was calculated at $34.9 million annually and $95,688 per day. Calculating the cost of producing one kg of cultured meat revealed it to be $63.69, with 59% of this cost attributed to culture medium and labor costs. Culture media contributes $19.7 to the production cost, while labor contributes $17.7. The production facility's maintenance and repair costs account for 8.6% of the total cost, and their contribution to the production price of 1 kg of meat is $5.47. Costs such as water, electricity, transportation, packaging, and borrowed operating capital have a relatively lower rate (2.88%, $1.83/kg). Bioreactors constitute 28% of the total cost and contribute $17.8 to the price of one kg of cultured meat. Building and property rentals, cold storage, information and technology infrastructure, and insurance account for less than 2% of the total cost and contribute $1.26 per kg. Garrison et al. (34) suggested sensitivity scenarios after the cost analysis. The first scenario (SC1) involves a 30% change in individual production costs, with all other variables being constant. The facility will operate 365 days a year, that is, with zero interruption. As a result, a 30% change in growth medium will have an impact on the total cost of $5.88, and the price of 1 kg of cultured meat will be $57.8 instead of $63.69. The impact of SC1 on total cost is most sensitive to the costs of growth media, labor, bioreactors, and processing equipment. The second scenario (SC2) was made about what the total cost would be if 36.5 days (10%) of the year were required for maintenance and repair activities in the facility and stand-in-place cleaning. As a result of this 10% increase in time, the production cost of 1 kg of meat increases by $4.22, bringing the price to $67.91. Furthermore, fixed costs such as building rentals, computer infrastructure, bioreactors, individual labor costs, working capital interest, processing equipment, cold storage, and insurance all increase. Because these costs are normally spread over a smaller number of production days per year, For example, the total cost of labor and extra rights increases by $1.96, from $17.65 to $19.62 per kilogram. In SC3, we calculate the impact of both the changes in SC1 and SC2 on the total cost, which includes a 10% increase in total outage days over the year and a 30% change in individual production costs. As a result of the 36.5-day increase in the days the facility is closed, the additional costs will be the same as SC2, but each production cost will have additional changes depending on the interpretation of each cost change. For example, the positive assumption they make about the cost of technology and cultural media in SC1 may be unreasonably high. In this case, a 30% change in the growth medium should be considered an increase in total cost. The 30% decrease in labor costs ($5.89) should be seen as reducing the total cost when considering labor and their extra rights. Various studies have been conducted to reduce the cost of production of cultured meat, and one of them is the potential scenario Specht (80) studied to reduce the cost of cell culture media. His scenario reports that reducing the cost of the culture medium can decrease the cost of 1 kg of cultured meat from $63 to $44.09 (80). If they reduce the bioreactor and labor costs by 25% in addition to the culture media costs in Specht's scenario, the price of one kg of meat is $35.09; if they reduce it by 50%, it will be $26.1; and if they reduce it by 75%, it will be $17.1 (all remaining costs are assumed to be constant). Even with considerable price decreases in these scenarios, simply reducing the cost of one factor that contributes significantly to the total cost remains insufficient to compete with the price of conventional meat; substantial savings must be achieved across all main costs (34).

***Alternative Production and Consumption Locations:*** Garrison et al. (34) found the cost of producing 1 kg of cultured meat to be $63, and production and consumption in this study were assumed to be in California (USA). However, countries like China and India can reduce this cost even further. More than half of the world's population lives in Asia (4.7 billion), and according to 2019 data, 2.83 billion of them live in China and India (90). In these countries, which may be advantageous compared to the USA in terms of labor costs, China may have 4% lower manufacturing labor costs than the United States, but cultured meat production can also appeal to low-income segments. It can also produce cultural media at a lower cost. However, they have to import bioreactors (34). As China's low labor costs approached US prices, companies turned to India. The minimum wage in India is 37% lower than in China (35). But transportation is expensive in India. Additionally, for some businesses, there are regulations that will make labor costs more expensive (8). Countries such as China and India may produce cultured meat at a much lower cost compared to the USA, but this reduction may not be as high as 30% (34). In Garrison et al.'s (34) study, it is estimated that the restaurant or supermarket price of cultured meat, which costs $63, will be over $100. Bioreactors, culture media, and labor costs alone total over $55. To produce at a lower cost, reducing the cost of the culture medium requires new technologies and innovations. Many countries do not approve cultured meat for human consumption, and when they do, it appears that it will be much more expensive than conventional meat.

***Market Trends:*** Cultured beef patties, which were produced for the first time in 2013 from cultured meat, attracted the attention of investors and the media, and the number of companies entering this sector has increased, especially in recent years. In one study, at least one of 32 cultured meat establishments had 25% interest in beef, 22% in chicken and duck meat, and 9% in pork and seafood (such as fish and shrimp). In addition, as an alternative to pet food, 2 businesses are looking into mouse meat, and 1 company is looking into kangaroo and horse meat. Of these 32 businesses, 40% are located in North America, 31% in Asia, 25% in Europe and 3% in Australia (19). Investors publicly disclosed almost 320 million US$ in cultured meat enterprises in 2015 and early 2020. Approximately 242.29 million US$ was allocated for beef and pork production, and 49.5 million USD was allocated for seafood. Many businesses can easily transition from producing animal products to poultry production, engaging in both simultaneously. While business-to-consumer is still the dominant business model, other business-to-business models have begun to take hold, including those that produce growth factors and media for cell culture, cell lines, cell production, or using fats as ingredients (19).

## Consumer Perspective

The success of cultured meat depends heavily on consumer perception selection, since consumer perception is a very essential factor in product selection (5). Due to this, numerous studies have been done to determine how customers feel about cultured meat.

In a study conducted by Wilks and Phillips (96), in which 673 people participated, 65.3% of the participants stated they would try cultured meat, 32.6% were willing to consume it regularly, 47.7% expressed they would rather consume cultured meat over soy-based meat alternatives, and 31.5% stated that they want to replace conventional meat with cultured meat. 11% of the 533 participants in a different research study said they would prefer cultured meat to conventional or plant-based meat (79). According to Hocquette et al. (39), 19.2% of 817 participants were eager to eat cultured meat. According to Bryant and Barnett (16), 66.4% of the 1,185 US participants would try cultured meat, 48.9% would routinely consume it, and 55.2% would choose it above conventional meat. According to Dupont and Fiebelkorn (28), 56.4% of participants (63.2% of males and 53.3% of females) were willing to eat the cultured meat burger. 54% of the 525 Italian participants were willing to sample cultured meat (51). A study by Weinrich et al. (95) found that 30% of respondents claimed they would like to routinely eat cultured meat.

In addition to this research, demographic patterns have a significant impact on how individuals feel about cultured meat. According to Wilks and Phillips (96), males, those with low incomes, and liberals were more enthusiastic about cultured meat. Males are more likely to ingest cultured meat, according to Slade's (79) research, which also found that younger and better educated people are likewise more likely to do so.

According to research, cultured meat consumption was more prevalent among males, younger people, and urban residents than it was among females, older people, and rural residents (88). Mancini and Antonioli (51) found that young, well-educated individuals knowledgeable about cultured meat and willing to reduce their meat consumption are the likely consumers of cultured meat.

Consumers largely opposed eating lab-raised meat due to its unnaturalness, safety, healthiness, flavor, and texture. The most prevalent misconception about cultured meat is that it is artificial. One of the elements impacting how cultured meat is perceived in comparison to conventional meat, according to Marcu et al. (52), is "natural and artificial." The notion that cultured meat is an artificial product appears to be a significant barrier to society's acceptance of cultured meat (48). According to Wilks and Phillips (96), there is general agreement that cultured meat is "unnatural" in comparison to conventional meat. Consumers in three European Union nations initially strongly reject and worry about the unnaturalness of cultured meat upon learning about it. Consumers acknowledged potential societal benefits on a global scale, but saw few direct personal benefits from cultured meat after consideration (92).

In a study conducted with participants from America, India, and China, 64.6% of the participants were willing to try cultured meat, 49.1% were willing to consume it regularly, and 48.5% were willing to consume conventional meat instead. And with these results, they concluded that cultured meat can replace conventional meat to a significant extent (16). However, in a study, one-third of the participants answered ‘’I don't know’’ and concluded that educated consumers in different countries would not routinely consume cultured meat (39). However, more research and education are crucial to altering how people view engineered meat.

Food safety is another common problem with cultured meats. Laestadius and Caldwell (48) reported some concerns that cultured meat may cause cancer and that cancerous cells may develop through cell proliferation. Hocquette (40) reported that these cells are unlikely to harm consumers as they die during digestion. In their study, O'Keefe et al. (56) demonstrated that consumers would only consider consuming cultured meat if its safety was confirmed. Verbeke et al. (92) stated in their study that people would prefer the safe to the unsafe.

Another common negative situation among consumers against cultured meat is the lack of flavor, appearance, and texture of conventional meat in cultured meat (88). Similar to this, Verbeke, Marcu, et al. (92) revealed that participants believed that cultured meat

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would taste terrible in their study. According to Hocquette et al. (39), just 23.6% of respondents thought cultured meat would be delectable, 39% disagreed, and 37.5% were unsure. In Slade's (79) study of 533 participants, nearly 90% thought that cultured meat tasted worse than conventional meat, although most thought it was superior to plant-based meat replacements.

Cost is another negative perception. Cultured meat would be more expensive than conventional meat (93). In the study of Wilks and Phillips (96), participants stated that they expected cultured meat to be cheaper. According to O'Keefe et al. (56), study participants thought that cultured meat should be more affordable to get wider adoption. Consumers may be influenced by price competition in real life, as a substantially lower price is a significant predictor of choice for cultured meat (79). Cultured meat's association with increased wealth disparities has been documented (12, 22, 82).

According to Bonny et al. (12), cultured meat will appeal to individuals with lower incomes, while wealthier people will still eat conventional meat. On the other hand, people worry that cultured meat, which is significantly more expensive than conventional meat, may allow the wealthy to consume meat without moral consequences, leaving only the poor to kill animals for a living (22). Cultured meat was initially only available in restaurants at exorbitant rates (67). Pricing is one factor that prevents customers from choosing cultured meat, which has the potential to have a significant impact on consumer behavior. The current price of cultured meat makes it possible to view cultured meat consumption as a luxury. Cultured meat production efficiency improvements may lead to it becoming more affordable than conventional meat in the future (31). But as cultured meat consumption increases, it may lose its opulent and prestigious structure.

Another important consideration is the ethical implications of cultured meat. According to Hocquette et al. (39), the majority of participants did not think that cultured meat would resolve issues with animal welfare in the livestock business. However, Wilks and Phillips (96) argued that cultured meat is ethical compared to conventional meat. In addition, due to the absence of the nervous system, cultured cells and cultured meat are believed to be painless, although animal biopsies to remove cells may increase concerns about animal welfare. Because it is a painless process, some scientists consider cultured meat to be vegetarian (17).

The goal of cultured meat is to produce meat with a lot fewer animals than traditional methods. Indeed, some vegetarians and vegans who want to cut back on their meat consumption for ethical reasons may find this to be appealing (42). One of the debates on this issue is the use of fetal bovine serum (FBS) when cultured meat is processed. In addition, some vegans avoid meat consumption because of its taste. Some vegans consider eating meat that can be produced without causing animal suffering. In the current situation, animals that are grown with or without pain are needed to produce cultured meat; that is, animals continue to be used to produce cultured meat (3).

Consumers also express negative attitudes related to religion. For Jews, it is a matter of debate whether cultured meat is kosher. Some Jews debate whether cultured meat can be considered Kosher, as they question if the cells can maintain their original identity regardless of the animal source (46). Islamic terms consider in vitro meat as Halal only if the stem cell comes from an animal slaughtered Halal and no blood or serum is used during the process (37). For Hindu consumers, the lack of animals to continue their rituals is a matter of concern (20).

In addition, attitudes toward cultural meat differ from country to country. For example, healthy nutrition has emerged as the most important factor for consumer acceptance in China (49). In a study conducted in Spain, the United Kingdom, the Dominican Republic, and Brazil, it was revealed that the cultural meat acceptance rate was 42% in Spain, 20% in the United Kingdom, 15% in the Dominican Republic, and 11.5% in Brazil. Researchers found that individuals with a traditional mindset are less accepting of new things (49).

Age is another important factor in the acceptance of cultured meat. Reports show that individuals aged 65 and above in Europe exhibit a greater interest in cultured meat, whereas young people globally demonstrate a higher acceptance rate (95). Furthermore, political orientation can be helpful when one wants to consume cultured meat. According to a study, liberals are more open to eating cultured meat than conservatives. Environmental issues and animal welfare also influenced liberals. Young people and city dwellers were also found to be influential among liberals (97).

It has been observed that education and socioeconomic status are also effective in influencing attitudes towards meat consumption. Low-income consumers in the United States found cultured meat more acceptable (96), while high-income individuals in New Zealand found it more acceptable (14).

## Future Prospect

Meat and other animal products have always been important in human nutrition (2). Although meat production has tripled in the last 50 years (71), the demand for cultured meat production may increase due to reasons such as the increase in the costs of resources such as land, energy, and water, the fact that the world population will increase much more, and the need to increase production by at least 70% to meet the increasing demand (19). In addition to these reasons, the traditional livestock industry's negative effects on the environment are another reason why people are interested in cultured meat. Another possible negative effect of traditional meat (especially red meat) is that it may negatively affect human health. There is increasing evidence that traditional meat can be linked to causes such as the emergence of chronic diseases in humans and an increased risk of early death (75). As a result, consumers have a common desire to produce more animal products that are environmentally sound, compatible with global food security, and more economical (21).

In the search for alternative meat, recent technologies have led to an increase in plant-based meat production. However, despite plant-based meats, traditional meat consumption is still important for many people. These problems in conventional meat production and the inability of plant-based meats to meet the required demand have led scientists to develop cultured meat production. Cultured meat seems to face some problems in its current state (70).

The consumer's perception of cultured meat currently consists of many factors, such as ethical values, nutritional content of meat, political opinion, education level, age, socioeconomic factors, and product familiarity (78). The majority of society is willing to ingest cultured meat, despite the fact that there are numerous opposing views regarding it in the current context (91). Consumers have various concerns for multiple reasons. The perception of unnaturalness caused by naming cultured meat as "in vitro," "synthetic," or "laboratory grown" (70) and the concern that various rituals will disappear (e.g., Thanksgiving turkeys) (15). However, because of its several advantages, including reducing animal suffering (38), providing protein to low-income populations, and enhancing animal welfare, it has great potential in the future (91).

Although the future of cultured meat looks good, it should not be forgotten that new technological developments are a risk, and moving away from traditional animal husbandry may have negative consequences (62). For example, rapid cell growth and division can increase the risk of mutations and potentially cancerous cells (82). However, Hocquette (40) asserts that while malignant cells may form in cultured meat, these cells will be dormant and unable to multiply until the user consumes that product. This means that it is unlikely to cause long-term harm to the consumer, although this is something that requires further investigation.

Traditional meat producers are often at risk of respiratory diseases and infections (75). In addition, there are negative consequences, such as people working in this sector having higher levels of stress and their mental health being negatively affected (75). It has been reported that cultured meat can prevent pathogens from passing from animals to humans and may be effective in preventing pandemics in the future (21, 43).

A switch to cultured meat could harm small-scale local meat producers and farmers, as well as widen the gap between rural and urban areas (76). Tubb and Seba (87) reported that plant-based meat alternatives could be five times cheaper than conventional meat by 2030, with a market shift of up to 40%. They also reported that the value of farmland could decrease by up to 80% in the United States alone. While cultured meat may soon be available on the market (70), there is also a view that plant-based alternatives could dominate the market at least until 2030 (44).

Another obstacle to the future of cultured meat is that it requires advanced production training and has a highly technical structure. To ensure cultured meat becomes as common as conventional meat in the future (82), we must seek answers to questions regarding the role of traditional producers and businesses in this sector, the long-term social, political, economic, ethical, and environmental effects of cultured meat, how information about cultured meat should be communicated, and how its proper location should be determined. Cultured meat's potential is great, but the industry's future remains complex and uncertain (62).

## Conclusion

Reasons such as its negative effects on the environment, the challenge of meeting future food demand as the population grows, and concerns about animal welfare may lead to the replacement of conventional animal husbandry with alternatives in the future. Today, meat alternatives produced from plant-based proteins and cultured meat can be produced, although not on a large scale.

Cultured meat has great potential in the future in many aspects, such as having fewer negative effects on the environment and using fewer resources than conventional meat, being able to eliminate food-borne zoonotic diseases, and animal welfare. However, problems such as cost, production difficulty, nutritional content, physical properties of meat such as texture, taste, color, and smell, and the perspective of some consumers on cultured meat also need to be overcome.

There are people who are very prejudiced about cultured meat, which is still not well known, and this may make it difficult to consume cultured meat as a meat alternative in the future. Practices such as increasing awareness about cultured meat, regulating costs, increasing the production scale, developing production methods and using new technologies in production, and determining marketing strategies according to countries may be important for cultured meat to take its place in the market as a meat alternative and its success in the market.

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## Conflict of Interest

The authors declared that there is no conflict of interest.

## Data Availability Statement

The data supporting this study's findings are available from the corresponding author upon reasonable request.

## Author Contributions

YA conceived and planned the concept and content of the review. AP, GİA, and ŞO contributed to the review and interpretation of the data. ŞO took the lead in writing the manuscript.

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