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THE FUTURE OF MEAT: EXPLORING CULTURED MEAT PRODUCTION

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ABSTRACT

Biotechnology and food science have embarked on a quest for alternative protein sources to meet the increasing food demands due to global population growth. Thus, the foundations of cultured meat production also referred to in the literature by various names such as synthetic meat, clean meat, laboratory meat, and in vitro meat, were laid. Cultured meat is the transformation of stem cells taken from the embryos or muscle tissues of animals into edible biomass in a laboratory environment using advanced technological methods. It is thought that the cultured meat production technology can reduce some problems such as land degradation, resource scarcity, slaughter and post slaughter contamination risks, and greenhouse gas increase in traditional meat production, depending on the technique and scale of the production technology. A full harmony has not yet been achieved between the nutritional content and taste of traditional meat and cultured meat. Differences in production technology and inputs also lead to differences in content and taste. The transfer of cultured meat to the production sector depends on its economic suitability, standardization of production, long term health effects, and consumer acceptance. Consumer acceptance is also affected by cultural, religious, and ethical concerns, as well as the same reasons. It is thought that having knowledge about cultured meat will also increase the acceptance. In this review, articles on the historical development of cultured meat, production methods, advantages and disadvantages, consumer acceptance, and its future in the food industry were used.

ETİN GELECEĞİ: KÜLTÜRLENMİŞ ET ÜRETİMİNİ KEŞFETMEK

Anahtar Kelimeler:
Yapay et, sentetik et, temiz et, kültürlenmiş et, laboratuvar eti, in vitro et

ÖZET

Biyoteknoloji ve gıda bilimi, küresel nüfus artışına bağlı olarak artan gıda taleplerini karşılamak için alternatif protein kaynakları arayışına girmiştir. Literatürde; sentetik veya yapay et, temiz et, laboratuvar eti, in vitro et gibi çeşitli isimlerle de ifade edilen kültürlenmiş et üretiminin temelleri böylelikle atılmıştır. Kültürlenmiş et, hayvanların embriyolarından veya kas dokularından alınan kök hücrelerin laboratuvar ortamında ileri teknolojik metotlarla yenilebilir biyokütleye dönüştürülmesidir. Kültürlenmiş et üretim

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teknolojisinin tekniğine ve ölçeğine bağlı olarak, geleneksel et üretimindeki arazi tahribatı, kaynak yetersizliği, kesim ve sonrası bulaşı riskleri ve sera gazı artışı gibi sorunlarının azaltılabileceği düşünülmektedir. Henüz geleneksel et ile kültürlenmiş etin besin içeriği ve lezzeti arasında tam manasıyla bir uyum sağlanmamıştır. Üretim teknolojisindeki ve girdilerdeki farklılıklar, içerik ve lezzette de farklara yol açmaktadır. Kültürlenmiş etin üretim sektörüne aktarılması, ürünün ekonomik uygunluğuna, üretiminin standardizasyonuna, uzun vadede sağlık üzerindeki etkilerine ve tüketici kabulüne bağlıdır. Tüketici kabulü ise aynı sebeplerin yanında, kültürel, dini ve etik kaygılardan da etkilenmektedir. Kültürlenmiş et hakkında bilgi sahibi olmanın, kabulü de arttıracağı düşünülmektedir. Bu derlemede, kültürlenmiş etin tarihsel gelişimi, üretim yöntemleri, avantaj ve dezavantajları, tüketici kabulü ve gıda endüstrisindeki geleceği konularındaki makalelerden yararlanılmıştır.

1. Introduction

Proteins are the most important building blocks in the human body after water. They are the fundamental components of cells and are made up of amino acids. Amino acids that cannot be produced by the human body, are essential for the continuation of vital functions, and can only be obtained through diet are called essential amino acids. Proteins are supplied to the body through foods of either plant based or animal based origin (Yetim and Tekiner, 2020). For adequate and balanced nutrition, plant based and animal based proteins should be equally incorporated into the daily diet. Meat, which is the most important source of animal based protein, contains many components essential for maintaining bodily functions (Atay et al., 2004). Red meat is rich in certain minerals such as phosphorus and iron, vitamins, and high quality proteins. Due to its composition, it is a food item with high biological value, delicious taste, and excellent nutritional properties (Yıbar and Çetin, 2014).

The carbohydrate heavy diet, preferred for its low cost and speed, was found to cause various diseases such as obesity, diabetes, and chronic fatigue, leading to a shift towards protein heavy diets. This change in eating habits in recent years has resulted in a significant increase in the consumption of protein rich foods (Çakaloğlu Ebcim et al., 2021). The human population is projected to reach 9.7 billion by 2050, and it is stated that the meat industry needs to increase its production by approximately 50-73% to meet the demand for meat. However, agricultural land and water resources required for production are limited (Choudhury et al., 2020). Moreover, traditional meat production systems lead to habitat and biodiversity loss, soil and water pollution, soil erosion, and an increase in greenhouse gases (Bhat, Kumar, and Bhat, 2017).

The increase in meat consumption due to population growth, along with the environmental concerns arising from this increase, has led to a search for alternative protein sources (Ko et al., 2021). As an alternative protein source, the first focus has been on plant based meat analogues produced from plants such as soy, wheat, and mushrooms (Okur et al., 2023). Plant based meat analogues, which are produced in the food market and accepted by consumers, constitute only a small portion of the total market. This is because they fail to deliver the desired taste and texture experience for most consumers (Hoek et al., 2011). Nowadays, alternative protein sources include algae, fungi, various plants, edible insects, single cell proteins, lab grown meat, dairy free vegan cheese, and other products produced through bio fermentation. These alternative sources need to be not only healthy, delicious, and affordable but also accepted by consumers from religious, cultural, and ethical perspectives. Serious studies must be conducted on these aspects as well (Ünver Alçay et al., 2018).

Cultured meat, one of the alternative protein sources, is produced by culturing stem cells taken from the muscle tissue or embryo of animals in a laboratory environment. It is also referred to by different names, such as lab grown meat, artificial meat, clean meat, or in vitro meat (Bhat et al., 2015).

2. Development Process of Cultured Meat

In their study, Bhat et al. (2019), discussed Alexis Carrel's growth of a piece of live chick heart muscle in a petri dish in 1912, Winston Churchill’s proposal for the use of cultured meat for human nutrition in his 1932 book Thoughts and Adventures, and the science fiction book Ravage, published in 1943, which describes the use of cultured meat in restaurants. The study also mentioned Willem van Eelen's idea in the 1950s to use tissue culture in meat production, for which he obtained a patent in 1999. In their research, Benjaminson et al. (2002), successfully cultured muscle tissues of goldfish (*Carassius auratus*) in a petri dish for use in long duration space missions. In 2011, scientists cultured turkey muscle cells using bovine serum and produced strips of turkey meat. In 2013, Dutch scientist Dr. Mark Post achieved a groundbreaking milestone by creating the world's first in vitro meat based burger. This lab produced burger marked a significant success as proof of concept. The study demonstrated that in vitro meat production is technically feasible and could serve as a potential alternative protein source in the future. The in vitro burger meat was evaluated sensory wise by two panelists at Riverside Studios, highlighting its resemblance to chicken meat in texture and its lack of color (Sürek and Uzun, 2020).

The first commercial production of cultured beef occurred in 2013, and since then, at least 35 trials of cultured meat using different animal cells have been conducted worldwide. Cultured meat production is primarily derived from fish, cattle, pigs, and poultry. In addition to these, experiments have also been carried out using animals such as horses, kangaroos, mice, and many others (Choudhury et al., 2020). In December 2020, a company named Eat Just launched cultured chicken meat for the first time in restaurants in Singapore. This made Singapore the first country to approve the sale of cultured meat (Yetim and Tekiner, 2020).

In Türkiye, the costly fetal bovine serum (FBS) is used in cultured meat production. To reduce costs, the Stem Cell Institute at Ankara University has developed a low cost serum alternative to FBS. In 2018, the company Biftek.co was founded in Türkiye as the first firm to work on cultured meat production in the country (Karasungur, 2021). Efforts to reduce the production cost of cultured meat in Türkiye continue.

Globally, companies like Mosa Meat, Super Meat, Memphis Meat, Modern Meadow, Finless Foods, Just, and Integriculture are pioneers in cultured meat production.

3. Cultured Meat Production

Cultured meat production refers to the production of edible meat in a laboratory using tissues and cells obtained from animals.
Laboratory produced meat is created using cell culture based techniques, tissue culture based techniques, and other specific methods (Future Food, 2020).

4. Cultured Meat Production Techniques

4.1. Cell Culture Based Technique (Scaffold Technique)

Embryonic myoblasts from the embryos of farm animals such as cattle, sheep, and pigs, or adult skeletal muscle cells from muscle biopsies of animals, are isolated. The isolated part is attached to a scaffold or a carrier like a collagen mesh within a stationary or rotating bioreactor. It is then cultivated in a plant based growth medium for weeks or months, allowing it to divide and multiply. The proliferating cells transform into muscle fibers on the scaffold within the bioreactor (Bhat et al., 2015; Bhat et al., 2017). Thus, the process of myogenesis (stem cell, myoblast, myotube, and myofibril formation) or muscle tissue development in the laboratory is completed, transitioning to the stage where the products are processed (Woll and Böhm, 2018). The steps of the scaffold technique are as follows:

Initially, tissue samples are collected from animals via biopsy, and stem cells are isolated through chemical breakdown of the tissue. Myoblasts are cultured in an appropriate medium and support structure. A plant based growth serum is used for myoblasts, which are then transferred to the bioreactor. In the bioreactor, they proliferate and differentiate. Cells transform into edible meat on the scaffold and are processed into the final product (Mateti et al., 2022). In this technique, cells are placed on a three dimensional scaffold, and the scaffold material guides the growth and differentiation of the cells, helping to achieve the desired tissue characteristics. By mimicking the different components of natural meat, such as muscle, fat, and connective tissue, it enables the production of more complex meat products like steak and fillet. Key factors in the scaffold technique include the composition of the culture medium, the growth factors present in the medium, and the choice of bioreactor, detailed as follows:

4.1.2. Culture Medium and Growth Factors

The culture medium used in the scaffold technique should contain nutrients such as amino acids, fatty acids, vitamins, trace elements, and extracellular vesicles to support cell growth. It must be easily accessible, cost effective, and edible while also promoting cell development effectively. This balance is crucial for optimizing the cultured meat production process (Aswad et al., 2016).

Growth factors are proteins and other molecules that promote the proliferation, differentiation, and maturation of cells. Natural growth factors are molecules produced by the body itself, regulating muscle development. Insulin like growth factor 1 (IGF1) is the most commonly used growth factor in cultured meat production. Artificial growth factors are typically synthetic versions of natural growth factors or similar molecules derived from other sources. The primary source of insulin like growth factor 1 (IGF1), which is essential for cultured meat production, is muscle cells. To enhance myoblast differentiation and fusion, scientists often reduce mitogenic growth factor levels. This induces the production of insulin like growth factor 2, which promotes differentiation and the formation of myotubes (Florini et al., 1991). Cell growth involves specific proportions of growth factors, inhibitors, and metabolic regulators. However, the precise serum components responsible for cell growth often remain unclear (Mannello and Tonti, 2007).

Research is ongoing to develop serum free synthetic culture media derived from bacterial extracts, yeast cells, fungi, or microalgae

(Ersoy, 2022). The scaffold used in the scaffold technique serves as a foundation for muscle cells to grow in an organized manner. It facilitates the efficient transport of nutrients and oxygen to the cells, ensuring their healthy development. Additionally, the scaffold influences the density and structure of the muscle tissue, contributing to the overall quality of the cultured meat. It allows control over the shape and size of the meat. The composition of the scaffold should have properties equivalent to the culture medium. Numerous biomaterials have been tested in scaffold production. When synthetic biomaterials were used, muscle tissue contraction became more challenging. However, successful results were achieved when collagen based scaffolds were utilized in cultured meat production (Snyman et al., 2013).

4.1.1. Bioreactor

Bioreactor setups are crucial for tissue regeneration. Fixed feature bioreactors are commonly used to culture cells seeded onto scaffolds within incubators, providing an appropriate growth environment. However, the development of new types of bioreactors is necessary for cultured meat production. These new bioreactors should be capable of stimulating tissue growth through high volume sample perfusion while ensuring low levels of shear stress, which is vital for maintaining cell health and achieving optimal tissue development (Martin et al., 2004). Cultured meat bioprocesses consist of four key stages: cell proliferation, differentiation, product formation, and waste management. Due to the complex environment required for cell proliferation and differentiation, these processes differ significantly from other bioprocesses (Schnitzler et al., 2016). Rotary wall vessels operating at speeds that balance centrifugal force, drag force, and gravity assist in developing tissue with characteristics comparable to in vivo conditions by submerging three dimensional culture media. Direct perfusion bioreactors have low shear stress and high mass transfer rates (Carrier et al., 2002).

4.2. Tissue Culture Based Technique (Self Organization Technique)

The tissue culture based method for cultured meat production involves forming muscle tissue in an environment as self organized structures or in vitro proliferation of existing muscle tissue, offering a highly structured approach to obtaining explanted animal muscle tissue (Benjaminson et al., 2002).

In this technique, the focus is on the proliferation and maturation of cells. The cells are grown directly in a nutrient medium, often resulting in simpler, irregularly structured products resembling ground or minced meat. However, forming more complex muscle structures like steak proves to be challenging. One of the key components of culture mediums, fetal bovine serum (FBS), is derived from the fetuses of pregnant cows. Its extraction process raises ethical concerns as it can cause pain and stress to animals. Moreover, FBS is a costly ingredient, making it essential to develop alternative, more cost effective growth factors and nutrient mediums for large scale production of cultured meat. In their research, Benjaminson et al. (2002), investigated the growth of muscle tissue cells isolated from goldfish (*Carassius auratus*) for producing animal protein for astronauts. Initially, the isolated tissue slices were minced, centrifuged, and placed in a petri dish for seven days, using nutrient media containing fetal bovine serum, Maitake mushroom extract, and goldfish skeletal muscle cells. The tissue showed approximately 14% growth with fetal bovine serum, over 13% with Maitake mushroom extract, and 79% with media containing goldfish skeletal muscle cells. The newly cultured tissue was marinated with olive oil and garlic, deep fried, and sent for sensory evaluation. Panelists noted that the tissues resembled fresh fish fillets in appearance and reported that the new tissue was edible in appearance and aroma.

Li et al. (2015), used pig muscle cells for tissue culture based cultured meat production. The cells were isolated, centrifuged to form pellets, and cultured in a petri dish for seven days in growth media containing fetal bovine serum with penicillin streptomycin and differentiation media containing horse serum. The tissue showed approximately 70% growth. Similarly, Wang et al. (2020), used goat skeletal muscle cells and reported tissue growth rates reaching 80% in media containing fetal bovine serum and horse serum.

4.3. 3D/4D Organ or Bioprinting Technique

Cultured meats produced through cell and tissue culture methods often fail to replicate the vascularization, texture, fatty tissues, and desired flavor of traditionally produced meats. Three dimensional (3D) and four dimensional (4D) bioprinting technologies utilize the principles of tissue engineering to mimic the anatomical, structural, and functional characteristics of natural organs or tissues, enabling the production of biological tissues. The stages of cultured meat production using the 3D bioprinting technique are as follows: Muscle is extracted from an animal through a biopsy. Myosatellite cells are isolated from the extracted muscle. A desired bioproduct prototype is designed using computer aided design software programs. The cells are proliferated in a nutrient serum medium and transferred to biocartridges. Biocartridges contain bio ink that includes thousands of living cells. Using these bio inks, components such as blood, muscle, and fat are naturally combined to create living tissue. The resulting tissue's protein, fat, and other nutrient contents can be adjusted as desired, achieving a realistic texture. Although the muscle tissue obtained through this process is promising, achieving the complexity of real muscle found in conventional meat is still not possible. Bioprinting techniques are categorized into three main types: inkjet based, laser assisted, and extrusion bioprinting (Balasubramanian et al., 2021; Mateti et al., 2022). 3D bioprinting is used to mimic specific tissue structures. However, over time, the change and development in tissue functionality remain limited. The 3D bioprinting technique has garnered significant demand in the cultured meat industry for cell printing due to its advantages of high speed, precise printing, and cost effective production (Okur et al., 2023). In the 4D bioprinting technique, the 3D bioprinting method is expanded, introducing an additional dimension over time. It promotes cell differentiation and tissue maturation. Over time, it enables the formation of blood vessels and the contraction of the produced muscle tissue. This approach allows for the repair of target organs and tissues sensitive to moisture and temperature, such as muscle, bone, and cardiovascular tissues (Javaid and Haleem, 2019).

Using the 3D bioprinting method, the world's first steak was produced in 2021 through collaboration between the Israel Institute of Technology and Aleph Farms. The cultured meat was reported to have a structure similar to traditional meat, containing comparable fat content, and was described as tender and juicy (Poinski, 2021).

4.4. Biophotonic Technique

The biophotonic technique is based on the effect of lasers moving matter particles into specific organizational structures. It is an emerging potential method in cultured meat production that uses light to connect particles. This technique not only moves particles to specific locations one by one but also has the ability to form structures from these particles. It offers an alternative to the scaffold technique for keeping cells together (Hopkins and Dacey, 2008).

4.5. Nanotechnology Technique

Nanotechnology is a novel technique that enables the production and modification of materials at the atomic and molecular levels. It is anticipated to be used in cultured meat production in the future. This technique involves designing molecular scale robots capable of manipulating matter at atomic and molecular levels. These robots can potentially produce cultured meat and many other desired products (Bhat et al., 2017).

Nanotechnology contributes indirectly to cultured meat production by enabling advancements in scaffold materials, facilitating the controlled release of growth factors through nanoparticles, and allowing the monitoring and control of production processes using nanosensors. These innovations improve efficiency, precision, and the overall quality of cultured meat.

5. Comparison of Traditional and Cultured Meat Production

5.1. Comparison of Production Processes

Traditional meat is produced solely through the slaughter of animals, whereas the production of cultured meat may require the slaughter of a few animals to obtain the initial stem cells. One of the ethical concerns in traditional meat production is the lack of consideration for animal welfare (Yetim and Tekiner, 2020). In cultured meat production technology, animal slaughter is avoided, ensuring animal welfare. However, it is argued that obtaining live cells or tissues from animals is ethically questionable (Gross, 2014). The use of FBS (fetal bovine serum) in cultured meat production imposes an additional burden on cattle farming, raising ethical concerns and posing a significant barrier to sustainability.

In traditional meat production, by products such as horns, hooves, skin, and bones are generated, which are not used for human nutrition (Ashley, 2002). In contrast, waste resulting from the care and slaughter of animals in traditional meat production is not produced in cultured meat production, a method based solely on the proliferation of muscle tissue (Datar and Betti, 2010). If cultured meat production can be scaled to an industrial level, it promises significant protein efficiency. The industrialization of cultured meat has not yet been achieved due to factors such as the lack of standardization in production conditions, high costs, and limited diversification of muscle tissue growth media (Bonny et al., 2015). Numerous studies are being conducted to address current issues with cultured meat and to introduce it as an alternative to traditional meat.

In one study aimed at improving the production process, researchers developed a sustainable scaffold free of animal derived components, with salmon gelatin, alginate, and agarose as its main components (Orellana et al., 2020). Another study focused on shortening cultured meat production introduced micro molds capable of producing edible film shaped scaffolds, reducing the muscle cell doubling time to as short as 18 hours (Acevedo et al., 2018). To further support muscle cell development, microcarriers commonly used in medical applications were modified, accelerating cell culture growth and reducing the production timeline for cultured meat (Bodiou et al., 2020).

Additionally, some researchers developed a novel temperature controlled air lift bioreactor to increase production capacity. This 300 m^3 bioreactor is estimated to meet the meat demands of 75,000 families (Xueliang et al., 2020).

5.2. Comparison of Environmental Impacts

It is believed that the greenhouse gas emissions caused by traditional meat production can be reduced through cultured meat production, potentially mitigating global warming (Hocquette, 2016). Traditional meat production is associated with significant greenhouse gas emissions, including carbon dioxide (9%), methane (39%), and nitrous oxide (65%) (FAO, 2006). Although researchers have not reached a consensus on the exact impact, it is estimated that approximately 18% of atmospheric greenhouse gases originate from livestock production (Pitesky et al., 2009). Additionally, ruminant animals account for 37% of total methane gas emissions (Hocquette et al., 2015; FAO, 2009). Traditional meat production involves extensive land use, high water consumption, and significant energy expenditure. Approximately two thirds of agricultural land is dedicated to producing animal feed, while only one third is used for cultivating plant based proteins, presenting a challenge in addressing global hunger (Welin and Van der Weele, 2012). Moreover, the production of 1 kg of pork requires 4 kg of animal feed, while 1 kg of poultry meat necessitates 2 kg of feed and 3918 m^3/ton of water. In contrast, producing 1 kg of red meat demands 7 kg of feed and 15500 m^3/ton of water. These figures highlight the inefficiency of traditional meat production methods (Datar and Betti, 2010). It is estimated that transitioning the meat industry from traditional to cultured meat production could lead to a reduction of 78-96% in greenhouse gas emissions, 99% in land use, and 82-96% in water pollution (Tuomisto and Teixeira de Mattos 2011; Tuomisto and Roy, 2012). However, the cell culture based technique used in cultured meat production requires significant energy. While cultured meat production reduces greenhouse gas emissions, water pollution, and land use, more extensive research is needed to address long term energy consumption concerns.

5.2. Comparison in Terms of Health, Nutrition, and Food Safety

During cultured meat production, it remains uncertain how all the nutrients present in traditional meat can be replicated. A valid production procedure has yet to be established. However, it is believed that once cultured meat production reaches an industrial scale, the nutrient content, composition, and quantity of the meat could be modified as desired (Chriki and Hocquette, 2020). Through cultured meat production, it is possible to modify the composition and quality of traditional meat. This includes enhancing its flavor, adjusting fatty acid composition and fat content, and specifically improving the ratio of saturated to unsaturated fatty acids to offer both taste and health benefits (Bhat et al., 2019). Furthermore, during the lab based production of meat, various health promoting and functional components can be added (Van Eelen, 2007).

Cultured meat techniques can also transform endangered species into new exotic meat varieties, and new types of meat can be developed for individuals with specific dietary preferences (Çakaloğlu Ebcim et al., 2021). Additionally, it is predicted that the risks associated with traditional meat production, such as exposure to hormones, antibiotics, pesticides, arsenic, and toxic compounds like dioxins, could be significantly reduced (Bryant and Barnett, 2018). Vitamin B12 is a crucial nutrient found exclusively in traditional meat, synthesized by gut bacteria. To incorporate Vitamin B12 into lab grown meat, supplementation is required. Similarly, iron, which is naturally present in traditional meat, can be added to the culture medium used in cultured meat production (Aisen et al., 2001).

Traditional meat production carries the risk of zoonotic diseases, which can be transmitted directly from animals to humans or indirectly through the consumption of animal derived products. Cultured meat, produced in a hygienic laboratory setting without direct contact with animals, eliminates the risk of zoonotic diseases (Hocquette et al., 2015). However, despite the controlled environment of cultured meat production, not all risks can be fully managed. Cultured meat production takes place in a controlled environment under strict hygienic conditions, resulting in meat with a significantly lower microbial load. This provides substantial protection against microbiological hazards that may arise during food preparation, cooking, or storage (Pandurangan and Kim, 2015). In contrast, traditional meat production carries higher microbial risks, not only from diseases that can be transmitted from animals to meat but also during the slaughter, post slaughter handling, and storage processes.

5.3. Comparison in Terms of Sensory Properties

In cultured meat production, oxygen in the culture medium suppresses the formation of myoglobin, which gives meat its red color, resulting in meat that is colorless compared to traditional meat. To add color to cultured meat, natural colorants such as beet juice and saffron are incorporated into the culture during production (Bhat et al., 2015). Direct myoglobin supplementation in the culture medium is also possible (Post and Hocquette, 2017). The product obtained through cultured meat production is muscle tissue. Biochemically, muscle tissue produced through cultured methods differs from traditionally produced meat (Datar and Betti, 2010). Traditional meat consists not only of muscle tissue but also includes other elements such as blood, nerves, and adipose tissue. Following slaughter in traditional meat, anaerobic glycolysis occurs, converting glycogen in the muscle into lactate. This process lowers the pH, activating enzymes that lead to biochemical changes, such as enzymatic proteolysis and protein denaturation, which influence the flavor, tenderness, and texture of the meat.

Since these processes are absent in cultured meat, sensory deficiencies emerge when compared to traditional meat, making consumer acceptance more challenging (Ertbjerg and Puolanne, 2017). Traditional meat must be aged for 1 to 2 days after rigor mortis for the desired texture to develop. Factors such as the myofibrillar structure, the quantity and composition of connective tissue in the muscle, and the amount and composition of fat contribute to the texture of the meat. To mimic this texture in cultured meat, the co culturing of myoblasts, fibroblasts, and adipocytes is necessary. However, current culture techniques face limitations in the distribution of nutrients and oxygen, restricting production to just a few layers of cells.

Due to the challenges in replicating traditional meat texture, cultured meat is often produced as finely minced or ground meat products (Fraeye et al., 2020). The flavor of traditional meat is derived from the complex interactions between the lipid fraction aromas in muscle tissue and carbohydrates and proteins. To approximate the flavor of traditional meat, cultured meat production must incorporate fat cells into the cell culture (Hocquette, 2016). However, cultured meat has yet to match the flavor profile of traditional meat (Zhang et al., 2020).

While advancing technologies promise numerous advantages for cultured meat production compared to traditional meat, current technology does not yet allow for replicating the intricate structural composition, texture, and flavor of real meat.

5.4. Comparison in Terms of Economic Impacts

Cultured meat production lacks a standardized process, and research continues to determine the most efficient stem cells, bioreactors, and processes (Alçay et al., 2018). Bioreactors act as the equivalent of blood vessels in traditional meat production, delivering nutrients and oxygen to muscle tissue (Pandurangan and Kim, 2015). However, during cultured meat production, tissue is cultured without homeostatic regulation, which affects its nutritional value (Datar and Betti, 2010). For industrial scale production, large capacity bioreactors are necessary, which significantly increase costs (Hocquette, 2016).

Producing steak like textured meat is challenging due to the difficulty in mimicking traditional meat's structure. Recently, various studies have explored the use of 3D printers to address this challenge, but the costs have not yet reached desired levels. As cultured meat production technology advances, costs are expected to decrease over time (Alçay et al., 2018). Myoblasts require a surface to grow and proliferate. In cultured meat production, the weak surface to volume ratio presents a challenge for scaling production to industrial levels. Processes such as scaling cell production and expanding tissue growth are costly and labor intensive when performed manually (Post and Hocquette, 2017).

Another major obstacle to industrializing cultured meat production is the high cost of the culture medium. Commonly used culture mediums include numerous nutrients, as well as animal derived components like fetal bovine serum (FBS). FBS is widely used for cell cultivation as it contains a variety of growth factors, hormones, vitamins, amino acids, fatty acids, and trace elements necessary for cell growth. However, its high cost and reliance on animal sources make it economically and ethically undesirable. Research continues to find alternative sources to replace FBS (Aswad et al., 2016). The traditional meat production industry is a vast sector employing a large number of people, including livestock farmers and agricultural workers. It not only supports the development of food sectors like meat, milk, and eggs but also provides raw materials such as wool, fibers, and leather for various industries. If cultured meat production reaches industrial levels, it is likely to give rise to economic challenges in multiple areas (Dumont et al., 2017).

The cost of the first cultured hamburger was $325,000. Mosa Meat, the company behind the first cultured hamburger, worked with the original team to reduce the production cost of cultured meat from $325,000 in 2013 to $112 in 2019. It is anticipated that over time, the cost of cultured hamburger meat could drop to as low as $9 (Chriki and Hocquette, 2020). To achieve industrial scale cultured meat production, an economically feasible and easily implementable process must be established (Bhat et al., 2015).

Currently, there are significant efforts underway in several countries focused on cultured meat production. However, the desired outcomes in production costs and retail pricing have not yet been achieved. Countries where cultured meat research is gaining momentum include the Netherlands, the United States, Israel, and Singapore. According to recent studies, cultured meat prices are expected to become affordable by 2025, and by 2030, cultured meat is projected to capture 10% of the meat industry market share (Bryant et al., 2020).

Although cost reductions are anticipated in various areas of cultured meat production, developments in scaffold and bioreactor design remain in their infancy. Consequently, large scale industrial production does not appear feasible in the near future.

5.5. Comparison in Terms of Ethics and Social Aspects

There are diverse ethical concerns and varied consumer opinions regarding the consumption of cultured meat. People who are highly prejudiced against the idea of lab produced meat are significantly influenced by the terminology used in its promotion (Bryant and Barnett, 2019). Several studies have been conducted to determine names that can positively impact consumer preferences, analyzing their effects on individuals (Çakaloğlu Ebcim et al., 2021). When the term cultured meat was used, participants generally responded negatively (Bekker et al., 2017). In studies conducted in the United States using the term lab grown meat, 20% of participants expressed willingness to consume it (Smith, 2021). In studies using the term clean meat, participants expressed that this term was more suitable and evoked a more positive reaction compared to names like cultured meat or pure meat (Çakaloğlu Ebcim et al., 2021). In another study conducted among Dutch participants using the term in vitro meat, 24% of respondents were definitely willing to try cultured or in vitro meat (Verbeke et al., 2015). Additionally, in separate research, 9.2-19.2% of participants indicated that they would purchase in vitro meat and responded positively to the term (Hocquette, 2016). In studies using the term synthetic meat, European participants emphasized its significant societal benefits for the environment and animals but expressed concerns about its impact on human health and the livelihoods of farmers (Verbeke et al., 2015; Marcu et al., 2015). Another study conducted in the UK revealed that 19% of participants had a positive attitude towards consuming the product referred to as artificial meat (Heid, 2021).

If cultured meat can be industrially produced, selected consumer surveys and notable concepts regarding its acceptance have been outlined (Candoğan and Özdemir, 2021). In Brazil, a survey conducted with 626 participants included an explanatory video about cultured meat. Participants perceived it positively in terms of animal welfare and environmental protection but highlighted concerns regarding ethical issues, affordability, and insufficient research (Valente et al., 2019).

In Italy, a survey involving 525 participants explained the production methods of cultured meat. Data from a university study was used to demonstrate its efficiency, and the term real meat was employed to emphasize its similarity to traditional meat. Participants expressed positive views regarding animal welfare, food safety, the need for environmental protection, and sustainability, but remained concerned about taste, nutrition, and food safety (Mancini and Antonioli, 2019).

In the United States, a survey with 480 participants highlighted cultured meat's production methods, claiming it has taste and nutrition comparable to real meat. Terms such as clean meat, in vitro meat, and cultured meat were used. While participants expressed positive opinions about taste and safety, they found the costs to be high (Bryant and Dillard, 2019). In the Dominican Republic and Spain, a survey of 401 participants was conducted without prior informational briefing. Participants expressed positive views on the necessity of environmental protection, animal welfare, and nutritional value but voiced negative opinions on food safety, price, and taste (Gomez Luciano et al., 2019).

In Switzerland, a survey involving 313 participants provided information on production methods for genetically modified meat/fish, edible coatings/films, cultured meat/milk, and synthetic food additives. Although participants appreciated the nutritional aspect, the unnatural nature of cultured meat caused concern (Egolf et al., 2019).

In Germany, a survey with 713 participants explained cultured meat production methods, its contribution to animal welfare, and highlighted that it is not yet available in supermarkets or butcher shops. Terms like in vitro meat, synthetic meat, and cultured meat were used in descriptions. Participants viewed cultured meat positively regarding its potential environmental and animal welfare benefits but raised concerns about its unnatural character and price (Weinrich et al., 2020). In a survey conducted in China with 1,004 participants, information was provided on cultured meat production, its health benefits, and its positive environmental impacts. Participants expressed favorable views regarding the necessity of environmental protection, but they shared negative opinions about its taste, nutritional value, food safety, and health aspects (Zhang et al., 2020).

In the Netherlands, a survey involving 193 participants discussed the negative environmental impacts of livestock farming, cultured meat production methods, and the claim that cultured meat's nutritional value, taste, smell, and appearance are similar to real meat. Participants believed cultured meat could have positive effects on environmental protection, animal welfare, taste, and food safety. However, concerns were raised regarding its high price and unfamiliarity (Rolland et al., 2020). Negative perceptions about cultured meat consumption are often linked to personal concerns, health related anxieties about cultured products, high costs, doubts over food safety, and the belief that it cannot replicate the expected traditional meat taste (Bryant and Barnett, 2018). Conversely, positive opinions stem from concerns about animal welfare, sustainability, and reducing environmental impact.

An additional, albeit rare, concern regarding cultured meat production is the perceived risk of culturing and proliferating human cells, which some fear could lead to scenarios resembling cannibalism (Schneider, 2013). The acceptance of cultured meat varies significantly across different cultures and religious beliefs. Opinions from religious and philosophical perspectives regarding cultured meat production remain unclear, which contributes to the ambiguity in consumer attitudes toward its consumption. This lack of clarity highlights the need for further dialogue and studies to address cultural and religious considerations, making it a critical area for ensuring broader consumer acceptance.

There is limited research regarding cultured meat production within the framework of Islamic law. Existing studies highlight that the halal or haram status of the animal from which stem cells are obtained, whether the cells are taken from a living or deceased animal, and the method of slaughter all influence its permissibility. From an Islamic perspective, the animal providing the stem cells must be religiously consumable, and cells must be taken after the animal is slaughtered following Islamic practices. Additionally, the culture medium must not contain any haram components (Yetim and Tekiner, 2020). The acceptance of cultured meat within Islam also hinges on obtaining halal certification, which requires strict adherence to Islamic rules regarding the source, slaughter, and processing of the meat. Transparency in the production processes and the components used is crucial.

In Judaism, similar criteria are applied when considering whether cultured meat can be deemed kosher, emphasizing strict adherence to dietary laws (Kenigsberg and Zivotofsky, 2020).

From a Hindu perspective, the use of animal cells for meat production is considered unethical and seen as an example of human arrogance (Yetim and Tekiner, 2020). Ethical concerns also revolve around how animals are utilized in cultured meat production and whether the process aligns with animal rights principles. The belief persists that cultured meat, being an artificial product, cannot replace natural meat. Additionally, the use of genetic engineering techniques in production raises questions about the ethical acceptability of genetically modified foods.

6. Conclusion

The limitations of resources in traditional meat production, along with land degradation, greenhouse gas emissions, excessive water and energy consumption, and the presence of animal related diseases, have led the scientific community to focus on cultured meat production. Cultured meat is anticipated to address key consumer expectations such as animal welfare, sustainability, and the preservation of human health.

Produced in hygienic laboratory conditions with a low microbial load, cultured meat is gaining favorable reactions from consumers for these reasons. The limited adoption of cultured meat consumption can be attributed to several factors. These include the inability to achieve the desired taste and texture, high costs, the need for advanced laboratory technologies, and the lack of large scale production capabilities. Additionally, the absence of standardized production protocols, insufficient regulatory frameworks and policies, and a lack of extensive sociocultural research further hinder its widespread acceptance.

Consumer preferences are also negatively impacted by the inadequate exploration of cultured meat from religious perspectives, leaving uncertainties that affect its acceptance within various communities.
Cultured meat production raises complex issues where concepts like halal in Islam and kosher in Judaism can conflict, particularly concerning materials and production processes. Transparency in the composition and production stages is crucial for establishing clear stances from a religious perspective.

Modern biotechnological methods like genetic modification and cell culture lead to varying interpretations, with debates on how genetic modification affects natural integrity still ongoing. For cell culture, the source and method of obtaining the cells are pivotal factors in religious acceptance.

From an environmental ethics perspective, cultured meat offers significant advantages, such as reduced resource use and lower greenhouse gas emissions. However, concerns about chemicals used in production and the energy consumed cannot be overlooked. While cultured meat aims to prevent animal death and suffering, ethical questions arise regarding how cells are sourced. Cultured meat is sometimes seen as an ethical dilemma stemming from humanity's desire to control nature.

Therefore, the overall benefits of cultured meat should be evaluated comprehensively, including its environmental impact, animal welfare implications, and human health effects. Your thought provoking questions reflect the central debates surrounding cultured meat and alternative protein sources. The idea of cultured meat as a solution to the global protein demand does raise questions about its scalability, affordability, and whether it can adequately meet nutritional needs compared to traditional meat or other protein rich alternatives like plant based products and insect proteins.

As for the sustainability proposals, understanding the entities driving these initiatives whether academic researchers, private companies, or environmental organizations is critical. Transparency around their motivations and how they envision reshaping the food systems is essential for evaluating whether cultured meat production aligns with global goals for equity, sustainability, and food security.

Whether cultured meat production is truly a necessity remains contested. Some argue that alternative solutions, such as transforming agricultural practices or diversifying protein sources, could achieve similar benefits without the technological complexities or ethical dilemmas posed by cultured meat.

Given these unresolved questions, the conversation around cultured meat and other alternative protein sources is bound to remain a significant topic in scientific, ethical, and social discussions for years to come. The acceptability of cultured meat as a food product is closely tied to factors such as reduced costs, a clear production process, comprehensive risk analyses, improved flavor, and the establishment of legal regulations. At this stage, cultured meat does not appear capable of dethroning traditional meat. Continued research into cultured meat is essential, and addressing consumer concerns with practical solutions remains critical. Providing accurate and reliable information to consumers and developing ethical standards are fundamental for fostering consumer acceptance.

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