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Challenges and Prospects in the Development of Cultured Meat: Addressing Nutrition, Quality, and Safety for Commercialization

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ABSTRACT

Lab-cultured meat, envisioned as a sustainable alternative to conventional meat, has emerged as a breakthrough technology with the potential to address the challenges posed by the rapidly growing global population. Cultured meat production involves the in vitro cultivation of stem cells derived from live animals, utilizing cutting-edge scientific advancements. However, achieving market-ready cultured meat products requires overcoming several hurdles. Key challenges include optimizing nutritional content, replicating the appealing texture, flavor, and color of conventional meat, and addressing the effects of processing methods on product quality. Furthermore, ensuring food safety is paramount, necessitating research on microbial load, genetically engineered starter materials, and strategies to mitigate potential risks. Despite these challenges, several manufacturers are actively working to develop commercialized lab-cultured meat products, paving the way for a transformative shift in the food industry.

Keywords: Cultured Meat, Protein Sources, Food Safety, Nutritional Aspects

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Introduction

Meat, defined as the edible parts of an animal's body, including lean tissue, fat, and organs, serves as a fundamental source of nourishment for humans. Historically, meat has played a significant role in human development and evolution, providing essential nutrients such as high-quality proteins that supply all necessary amino acids required for vital physiological functions. Additionally, it is a rich source of fatty acids and various micronutrients. Beyond its nutritional value, the flavor of meat holds significant cultural and social importance in societies around the world [1]. The rapid growth of the global population has led to an increasing demand for meat to meet the nutritional needs of expanding societies. However, scaling up traditional meat production to satisfy future demand is becoming increasingly unsustainable due to limited land and water resources, as well as its adverse impacts on the environment and climate change. To address this challenge, the development of alternative protein sources is essential. One promising solution is lab-grown meat, a technology that eliminates the need for animal rearing by utilizing unspecialized stem cells with self-renewing capabilities. Lab-grown meat, a key innovation within the emerging field of cellular agriculture, involves extracting animal tissue cells and culturing them aseptically in highly controlled environments to facilitate cell growth and tissue development. This process not only addresses the global meat shortage but also meets the growing demand for protein while mitigating environmental issues associated with traditional meat production, such as waste-related contamination and meat-borne illnesses. Lab-grown meat represents a transformative approach to sustainable food production and holds the potential to reshape the future of global nutrition [2].

This approach simply involves muscle tissues culturing in an unnatural medium, from animal stem cells on a larger scale, myosatellite generated from animal embryos and biopsy of muscles exposed by enzymatic reactions, and culturing of loose cells of myosatellite on substrate [3]. The cultured meat concept for consumption by humans was first introduced by Churchill and published in 1932, in the book named “Book of Thought and Adventures”. The writer and a politician named Frederick Smith predicted that “there will be no requirement for lengthy rearing process for eating a steak”. William Eelen had the notion of using culturing of tissue for the development of lab-scaled meat in the early 1950s. That idea for tissue culturing was the starting of the production of lab meat from stem cells. A frog muscle biopsy was done and kept that matter alive, propagated, and developed a new culture system. The first cultured meat symposium was held in 2008 in Norway, projected the first cultured meat product. After that Professor Mark at Maastricht University revealed about the world’s first burger made from lab-prepared meat from cow stem cells. It took about three and half months to grow in a laboratory. Due to the declining credibility of industrial farming, cultured meat emerges as a viable solution to address practical challenges and ethical concerns associated with conventional farming practices. Researchers argue that the production of standard meat by totally avoiding the death of the animal, removal of cells from the animal through biopsy, and growing those cells in the medium may be more ethical than conventional meat in which slaughtering is compulsory [4].

Production Mechanism

Production of lab-scaled meat describes the creation of meat without slaughtering the animal, and represents products, made from cultured meat are generally made of those cells using the techniques of tissue engineering. The meat cultivation process has two different phases with definite goals: proliferation is phase one, designed to acquire the maximum number of cells from a cluster of cells, and the second phase is the differentiation stage and maturation stage, where cells are admitted to grown in cells of skeletal muscles as represented in figure 1[3].

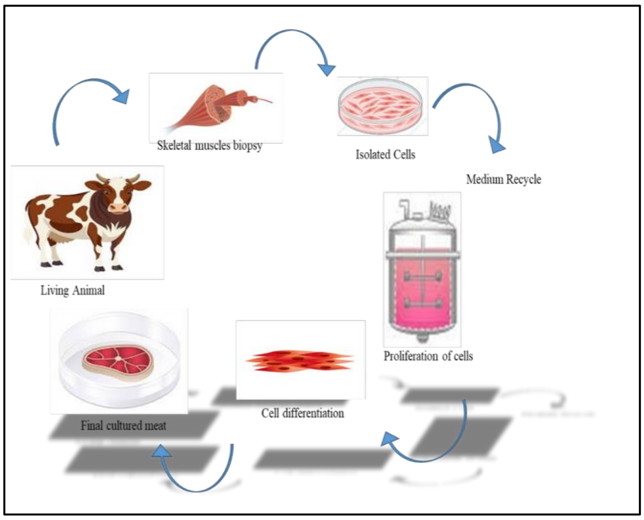

Fig. 1: Production Process of Cultured Meat

Benefits of Cultured Meat

Mitigate Animal Suffering

The production system of cultured meat is a commitment to supply protein sources to fulfill global demands for meat, which would alleviate the millions of animals slaughtered. Animals' need for tissue culturing is less than for regular production of meat.

Food Safety

Some researchers advocate that cultured meat is safer than ordinary meat for consumption by humans. Because animals who are slaughtered, have continual contact with their contaminated environment and have deadly pathogens like E. coli and Salmonella in gastrointestinal tract. These pathogens can be moved during slaughtering. In context with cultured meat, it is grown in a bioreactor tank which is sterile and alleviates the chances of occurrence of disease [5]. Furthermore, ordinary meat reduces the resistance of antibiotics for pathogens, which might be a result of the extensive use of antibiotics. In contrast, lab-scaled meat is handled in a sterile environment and eliminates the chances of infusions of any infections. Two types of meat, named Memphis and Mosa meat, assert that both of them don't need any type of antibiotics because of sterile lab procedures [6].

Supportable Environment

In conventional production of meat, 6%-26% of animals are processed as consumable meat. It will cause many problems with a substantial fragment of gas emissions of greenhouses, usage of land, energy, and water. In comparison with cultured meat, 79%-97% less emissions of greenhouse gases, 99% less usage of land, and 90% less usage of water. Lab-scaled meat is an eco-friendly and supportive means of meat production to alleviate larger population stress and satisfy protein demand [7].

Challenges in the Production of Cultured Meat

Capacity of Bioreactor

The competitive food market. While the production process for cultured meat has advanced significantly over time, several challenges remain in scaling production to industrial levels. A critical component of this process is the expansion and differentiation of cells, which is typically carried out in bioreactors. For example, to cultivate muscle cells at a density of approximately 8×10^{12}, bioreactors with a capacity of around 5,000 liters are required. In the initial stages of cultured meat development, such as the production of the first cultured burgers, smaller bioreactors were utilized for cell cultivation. These small-scale systems demonstrated proof of concept but are not sufficient for meeting the demands of large-scale commercialization [8].

Conditions of Culture and Cell Line

Scaling stem cells to the required quantity and differentiating them into targeted tissues remains a significant challenge in cultured meat production. Commonly used cell lines include muscle cells, mesenchymal stem cells, and embryonic stem cells. Among these, embryonic stem cells offer the advantage of an unlimited supply, but they are notoriously difficult to access and handle. Muscle cells, on the other hand, naturally possess the ability to differentiate and form tissues, making them a promising option. However, their potential is limited by a finite number of passages during cell culture. Similarly, most stem cells have restricted proliferation capacities, typically dividing only 40–60 times [9].

Development of Animal Serum

Animal serum has been traditionally used as a standard nutrient medium for culturing cells derived from newborns, adults, and fetuses. However, the use of serum poses several challenges. It is highly expensive, making it unsuitable for cost-effective large-scale production. Additionally, its use raises ethical and religious concerns, as well as conflicts with certain dietary preferences [10].

Scaffold Matter

The thickness of cell culture acquired by utilizing scaffold matter is another critical issue in the processing of culture. Cells tend to die at a thickness of approximately 200 micrometers due to insufficient oxygen diffusion and nutrient delivery to the inner layers. This measurement is inadequate for meat processing, so sizeable pieces of tissues for culturing are required [11].

Product Quality

Cultured meat has slack and amorphous formation, poor taste, and poor chewiness. Recent techniques of culturing can't guarantee a good texture and taste. Conventional meat comprises bioactive components like immunoglobulins and some growth factors, in comparison with cultured meat. Cultured meat is supplemented with different additives to give sensory qualities. Some amounts of fat are incorporated to enhance taste, and edible adhesive is used to boost the shape of tissue. Nutritional value is also enhanced by adding some micronutrients [12].

Production Cost

The input cost decides the price in the market of produce, which directly influences the purchasing decision of consumers. The first product made from cultured meat was a burger, a worldwide attraction, worth dollar 330,000, which was a very high price. Improvement in technologies leading to reducing the price of products is essential for market acceptance of cultured meat [13].

Global Market of Cultured Meat

The global in vitro meat market survey describes the global in vitro market of meat as divided into six classes, basically on geographical bases, Asia Pacific, Middle East, North America, Europe, South America, and Africa. Based on geographical placement, Europe and North America developed the industry of cultured meat. Developing regions majorly concentrated on laboratory experimentations. According to surveys, it is anticipated that North America will influence the global cultured meat market, because of greater technological adaptations by the food industry. The regional market of Asia Pacific is anticipated to grow, due to high meet demands, advancements in technologies, and high level of investments in this industry [11].

Nutritional Profile of Cultured Meat

It is a general consideration that meat is a nutritious food item due to its high protein content with a high amino acid score, minerals, and vitamin profile. The composition of macronutrients is influenced by scaffold matter. Collagen, which is a structural protein, is used in engineering methods of muscle tissues. Collagens have usually an amino acid profile which is non-essential, but also contains an adequate amount of lysine, which is a limited amino acid in regular diet. The amount of lysine in connective tissues is different, post-transcriptionally changed to hydroxylysine, and can't be utilized in the synthesis of protein. The determination of lysine and hydroxyl lysine is dependent on the source of collagen either animal or recombinant. Collagen usually makes up the least fragment in lean meat, but it comprises 25% in terms of processed meat.

The composition of fatty acids in meat is influenced by certain factors such as species, type of diet, age, and cut of meat. Fat contents of meat are influenced mainly by product calorie density, the composition of fatty acids impacts dietary value such as saturated fats and unsaturated fats, PUFA ratio, and Trans fats. Fatty acid addition in cultured meat can be followed through adipocyte co-culture obtained from stem cells of adipose, which could produce different unsaturated and saturated fats. Essential fats such as omega 3 and omega 6 present in conventional meat, are still absent in cultured meat as mentioned in figure 2. Further research is required to identify whether the composition of fatty acid in adipocyte culture may be controlled by adding essential fats in media without any growth disruption and lipogenesis.

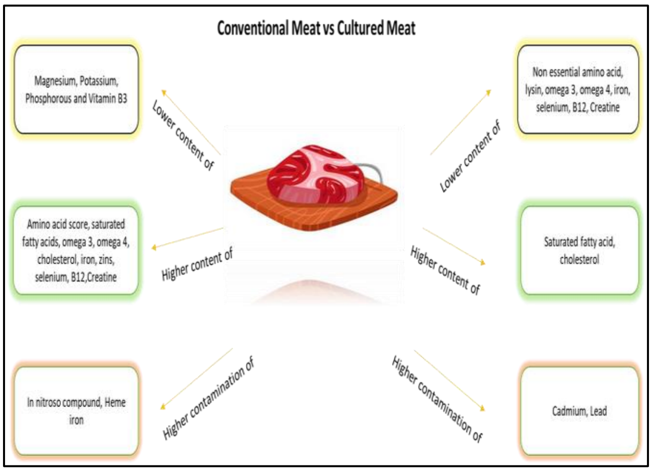

Fig. 2: Comparison of nutritional profile in conventional meat and cultured meat

Ample minerals are present in conventional meat but are still absent in cell-cultured media and there is a dire need to supplement these minerals to support the growth of cells. Conventional meat also gives a wide range of B vitamins; cultured meat is considered to be an alternative to regular meat, it must be included with vitamin B12. Conventional meat also has a larger array of bioactive compounds. Taurine is present in meat which helps in various metabolic processes and conditions in cell cultures are deficient in taurine [13].

Conclusion and Future Aspects

The practicality of lab-scale meat manufacturing can resolve many issues related to the production of conventional meat. Many technological challenges are faced in the production of cultured meat and available production conditions infer that lab-scale meat varies remarkably from conventional meat in nutritional contents, sensorial, and technological properties. There is a dire need for long-term research on the composition of cultured meat to increase its acceptability. There are many technical and scientific issues regarding the production of a complete spectrum of lab-scale meat, ideas warrants the rise of the strong scientific and educational direction of the bio-based economy in upcoming decades.

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