**Cultivated Meat: A Sustainable Alternative to Conventional Protein Source**

**Abstract**

Conventional livestock farming systems have created long-term effects on our natural resources such as water, land, loss of biodiversity, and even contribute to greenhouse gas emissions which requires a radical shift to a more feasible and sustainable solution. One such technique that can offer a way to decrease the impact on the environment and to satisfy the growing food demand for the growing population is cell-based meat or cultivated meat or cultured meat which requires cell culturing animal cells *in-vitro*. Many start-ups have emerged all over the globe to develop cultured meat technology yet are not in a position to bring it into the commercialization stage due to certain constraints like production cost, consumer acceptance, stringent regulatory requirements, etc. Moreover, many researchers have started working on optimized formulations, and serum-free, food-grade components to further reduce the costs of cell culture media which accounts for more than 90% of the total production cost. Apart from economics, food neophobia, being one of the main factors of consumer perception and acceptance due to limited knowledge could be solved by providing awareness citing its strong potential to contribute to ensuring [food security](https://www.sciencedirect.com/topics/food-science/food-security), nutrition, health concerns, reduction of carbon, and sustainability to enhance the overall acceptability of the cultivated meat technology.

**Keywords:** Livestock, Conventional farming, Sustainable and Cultured meat.

**Introduction**

The global population has already crossed 8 billion people according to the United Nations World Population Prospects 2022 report (Gerland *et al.,* 2022). As a result, the future demand for food production and distribution must be fulfilled to feed the growing global population to prevent hunger and human suffering (Nature communication, 2024). In the Indian context, nearly 35% of the total dietary protein requirement is provided by the consumption of meat alone and is projected to rise shortly (Kamalapuram *et al.*, 2021). Food security problems are still prevalent in India due to many reasons such as limited land resources, climate change, unsustainable agricultural practices, inadequate storage facilities, etc. (Upadhyay and Palanivel, 2011). Therefore, the search for new and effective solutions has led scientists and researchers to shift to a far more sustainable, innovative, and secure food system such as cultured/cultivated meat/lab-grown meat.

Cultivated meat is meat that is produced by extracting and cultivating animals’ cells in a controlled laboratory environment (Dvash and Lavon, 2023). In other words, it is the application of tissue engineering techniques for meat production. It’s a genuine meat (as shown in Fig. 1) but it requires no animals to be bred, fed, and slaughtered as the conventional method of meat production does thereby providing lesser consumption of energy, land, and water (Treich, 2021). Contamination is considered negligible since the lab-grown meat is produced in a fully controlled laboratory environment free from harmful microbes and are devoid of growth hormones and antibiotics which are often injected in farm animals (Powell *et al.,* 2025). Moreover, the nutritional contents of lab-grown meat may be altered and modified to make it healthier by changing the composition of culture medium, fatty acid, and nutrients (Amin *et al*., 2021). For example, replacing harmful fats with healthy fats like omega-3 can prevent cardiovascular disease and risks of exposure to other hazards associated with conventional meat production systems like pesticides, arsenic, dioxins, and hormones could be significantly reduced due to strict quality control rules (Bhat *et al.*, 2015). Fig. 2 shows the simple schematic diagram of cultured meat production.



**Figure. 1 Cultivated meat (Image Source: Vegansustainabiliyy.com/the facts about cultured meat – Image accessed on 10/01/24)**



**Fig 2. Schematic of cultured meat production (**Adapted from Gaydhane *et al.*, 2018)

**Inputs required for cultivated meat**

The inputs that are required to cultivate meat are as follows (Broucke *et al*., 2023)

1. Cell line source: Cell lines can be procured through a biopsy on an animal after administering local anesthesia or through cryo-preserved cultures.

2. Cell culture growth media: The extracted cells are placed in a controlled and sterile manner in the cell culture media containing many components such as vitamins, amino acids, glucose, inorganic salts, and growth factors.

3. Bioreactor: Cells are allowed to grow in a bioreactor until they proliferate enough to form a suitable amount of meat for harvesting.

4. Scaffold: It may be materials (i.e. hydrogel, collagen, mycelium) and tissue construction techniques (i.e. 3D printing/additive manufacturing, electro-spinning) used to turn a slurry of cells into meat products.

**Global scenario of cultivated meat**

Manufacturing of cultivated meat with the current focus group of products is shown in Fig. 3. According to the 2021 State of the Industry report (Good Food Institute), a total of more than 100 companies all over the globe (Fig. 4) have been involved in cultured meat production. Some of the lab-grown meat companies leading the cultured meat revolution are shown in Table 1 below. Wealthy investors are paying attention to the potential of cultured meat and have witnessed major investments such as Cargill’s investment into Memphis Meats and Aleph Farms, and Tyson Foods into Memphis Meats, and Future Meat companies. Moreover, the first public-sector R&D funding awards between the US and the European Union on cultured meat have been made (Global cultured meat market analysis report, 2022). It is worth mentioning that cultured meat has begun hitting the market; Singapore became the first country to approve the sale and consumption of cultured meat product (chicken) in 2020 for use in the preparation of chicken nuggets which was manufactured by US-based company Eat Just (Hong *et al*., 2021). In India, Clear Meat and Ahimsa Meat are the two companies focussing on developing lab-grown meat to provide a healthy, sustainable, and affordable meat alternative. Moreover, the Humane Society International (HIS) and the Centre for Cellular and Molecular Biology (CCMB), Hyderabad have joined hands for the development of cultured meat in India and are expected to make it available in India commercially by 2025 (Bharati, 2022).

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**Fig. 3 Current focus for cultivated meat production**

**Fig 4. Distribution of cultivated meat-producing companies globally.**

**(source: 2021 State of the Industry report-cultivated meat and seafood, Good Food Institute)**

**Table 1. Some of the leading cultured meat-producing companies**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sl. No** | **Company Name** | **Founded** | **Country** | **Focus** |
| 1 | Because Animals | 2018 | USA | Pet food |
| 2 | Aleph Farms | 2017 | Israel | Beef |
| 3 | Shiok Meats | 2018 | Singapore | Shrimp |
| 4 | Wild Type | 2016 | USA | Salmon |
| 5 | Biftek | 2018 | Turkey | Culture media |
| 6 | Avant Meats | 2018 | Hong Kong | Fish Protein |
| 7 | Upside Foods/Memphis Meats | 2015 | USA | Poultry |
| 8 | SuperMeat | 2015 | Israel | Poultry |
| 9 | Mosa Meat | 2015 | Netherlands | Beef |
| 10 | Cubiq Foods | 2018 | Spain | Fat |

Source: List of companies creating lab-grown meat (retrieved from [www.labgrownmeat.com.](http://www.labgrownmeat.com.))

**Technological advancement**

Production of cultivated meat is still in the early stage despite continuous efforts made by several companies due to a lack of standardization of the raw materials to be used such as cell lines sources, culture media, and scaffolding materials (Bryant, 2020). Initially, standard serum solely extracted from the unborn fetus of the bovine was used which then later shifted to an alternative source that is serum-free media due to ethical concerns (Kolkmann, 2020). However, the use of serum-free media requires an additional growth factor which is made from recombinant protein for cell growth (Mainali *et al*., 2025). These growth factors are usually depleted soon during the cultivation process in the media due to their low shelf-life and need to be exchanged every few days. The main constraint here again is that currently the growth factors are supplied by the industries which is quite costly accounting for up to 90% of the cost of cultivated meat production limiting the availability of the final product at an affordable price by the producers (Specht, 2020).

Efforts are being made by several researchers to accelerate the production keeping the cost of production to the minimum possible by modifying the cell growth pathway or mode of expression of the growth factors within the cell (O’Neill, 2021). Stout *et al*. (2024) developed a bovine muscle cell that can produce its growth factors. They also stated that the method will work for other meats based as fish, poultry, and pork. This advancement has given hope for cultured meat technology to bring closer to seeing cultivated meat at affordable prices in supermarkets shortly.

Biomaterial substrates like scaffolds, microcarriers, or films are utilized for seeding the muscle cells and further cell proliferation to grow into tissue structures and textures similar to conventional meat (Lu *et al.,* 2022). Their availability and cost are also the key factors for the production of cultured meat. They can be derived from plants, microorganisms, animals, and synthetic polymers (Fasciano *et al*., 2024). Xiang *et al.,* 2023 have fabricated several edible and biodegradable scaffold biomaterial films such as gelatin, soy, glutenin, zein, cellulose, alginate, konjac gum, and chitosan and compared their properties. They found that the protein-based films-glutenin and zein provided better adhesion, proliferation and differentiation, and mechanical properties of the bovine and murine cells which showed a promising material to be used for cultivated meat production. Wei *et al*. (2023) developed a soy protein amyloid fibril scaffold and demonstrated their potential to be utilized for cultivating meat due to their proliferation and differentiation ability without any cell adhesive or coatings. A recent study by Santos *et al*. (2024) reports on random cellulose acetate nanofibers scaffold as a promising and remarkable potential solution for cultivating and producing thick muscle tissue of different cell lines without the need for surface treatment or coating treatment due to their porous nature and its ability to induce differentiation, high cell viability upon stacking.

**Regulatory legislation**

Many new processes or cultured meat products are developed by different companies but the main focus is the safety concerns which will serve as the main turning point of overall acceptability. Therefore, before being open for sale regulations for the approval of such products by different concerned food agencies need to be made. In the USA, both the FDA (Food and Drug Administration) and USDA (United States Department of Agriculture) has joined hands in the regulation of cultivated meat (Gottlieb, 2018). Singapore Food Agency has also published food safety assessment guidelines regarding cultivated meat (Singapore Food Agency, 2022). A more recent report on the prohibition of the production, import, and export of food derived from animal cells has emerged from the Italian government due to their robust regulatory process which may hold back the progress of cultivated meat technology and its future research and development activities (Good Food Institute Europe, 2023).

**Consumer acceptance**

The willingness to switch to cultured or cultivated meat from conventional meat without prior knowledge of consumption history is not an easy decision to take into consideration by the vast majority of the population. However, giving awareness considering the benefits it may provide in terms of quality (taste, appearance, tenderness) and nutrition similar to conventional meat, animal welfare, risk of emerging infectious diseases associated with the live animals, relatively low impact on the environment can help facilitate the acceptance level (Bryant & Barnett, 2018). Having said that doubt and fear may still be present among food neophobia due to the unnatural process of meat cultivation in the laboratory due to their limited knowledge and opportunity (Szejda, 2021). A quantitative study was conducted by Silva and Pereira (2022) with 304 Brazilian consumers to find the factors affecting the consumer's intention to purchase cultivated meat. Results showed that clean production and food safety favoured them to purchase the cultivated meat but the naturalness and food neophobia had a negative influence on buying intention. A nationwide survey conducted by Fu *et al*. (2023) from 410 U.S. consumers confirmed that 50% of the participants strongly agree with the fact that cultivated meat is unnatural. However, unnaturalness was not the main inhibitor to acceptance but food neophobia. They suggested that consumers should be educated on the science behind the production, its potential benefits, and sustainability appeal to enhance the acceptance. Similar results were found from another survey conducted by Baum *et al*. (2023) from 727 German consumers where food technology neophobia was the main significant factor inhibiting acceptance.

**Future strategy**

Consumer acceptance is the main target to deal with to achieve widespread commercialization of cultivated meat (Bryant and Barnett, 2018) To begin with, proper regulation and legislation systems should be imposed to address the food safety concerns that could guarantee their safety (Stephens, 2018). In addition, the promoters should maintain an effective trustworthy labelling of the product without using any technical terms. Further, awareness campaigns or programs should be conducted regarding the potential benefits, health concerns, quality, relative environmental impact, and sustainable alternative solutions to the conventional system.

**Conclusion**

The overgrowing population and degrading natural resources are causing the problem of food insecurity throughout the world. To solve the rising demand for food, many academicians, researchers, scientists, investors, etc have collaboratively worked tirelessly on different innovative and sustainable technologies to find a secure and stable solution for achieving food security worldwide. The cultured meat technology is one such promising solution that has seen a rapid rise in the number of start-ups globally for developing cultured meat over the last five years. Despite having attained a remarkable development in this technology, most of the companies are not currently in the position to reach the commercialization stage, and regulatory approval by the country’s concerned authority needs to be achieved for an effective food control system. In addition, it is inevitable to focus on taste, higher quality, higher yields, lower consumer costs, and lower environmental impact for better public and market acceptance.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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