Future Trends in Lab Grown Meat from Stem Cell

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Abstract

As the population increases the demand for meat also increases, people are well aware of their nutritional needs and meat is a rich source of protein. But people are also concerned with the animal's welfare and want to fulfil their needs. To overcome this problem lab-grown meat from stem cells is a good initiative which will also increase as people's demand and awareness increase without sacrificing animals. Lab-grown meat from stem cells is actively researched as it represents the cellular product of cellular agriculture due to ethical concerns, environmental factors, and global food security. For market entry understanding stem cell meat and establishing the safety regulations and standards are necessary and crucial. To develop high-quality cultured meat at a wide scale we need high throughput technology but also consider the fact lab-grown meat is still in the early stages because of consumer acceptance and limitations in technology. Understanding the techniques, technology and regulations of cultured meat will open new ways for cellular technologies and help the growth of country's economy.

Keywords: Lab-based meat, Cultured meat, Animal welfare, Stem Cell, Livestock industry, Future trends

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Introduction

The most important source of feed for humans is meat which is "muscle tissue of slaughtered animals" (Heinz & Hautzinger, 2007) because of its nutritional properties and benefits for human health (Wyness et al., 2011). Approximately world population by 2050 will be almost 10 billion and there will be not enough production from conventional methods to fulfil the nourishment requirements of people globally (Eibl et al., 2021). The renowned British statesman, Winston Churchill (Churchill, 2016) indicated that in the future tissues of chicken muscles would be grown independently, by eliminating the devoid to raise chickens. This groundbreaking idea set the beginning of a journey into the realm of cultured meat production. Various researchers have described the possibility of growing meat in labs, as years pass, paving the way for an insurgent approach to food technology. Known as cultured as well as in vitro meat, under controlled conditions cultivated animal tissues grow in laboratories in this method. This provides the solution for many challenges related to traditional meat (Wang & Rudnicki, 2012).

One of the most potential solutions to solve the future problems of food security is cultured meat, which is the spiralling field of agribiotechnology, uses culturing microbes, animal & plant tissue and cells to produce agricultural products (Rischer et al., 2020). Like for the meat industry, consumer satisfaction and preferences are the most important concerns. Consumers' beliefs and behaviour mainly affect the product itself because of the negative image like its connection with the living animal, environmental issues, ideological and moral concerns and the slaughter conditions. So, changes in food production are required as unconventional protein-rich products are increasing in popularity among consumers. Because changes in the eating behavior enforces livestock farming and agriculture to bring the evolving period (Sharma et al., 2015). Foodborne illness is caused due to inappropriate animal welfare conditions so, cultured meat will reduce the growth of animals on farm so there will be no problem with animal welfare and reduce chances of foodborne illnesses from harmful pathogens like Salmonellosis and *E. coli* (Ben-Arye & Levenberg, 2019).

Cultured meat serves different advantages like competition to other protein products, needs no large space for animal upbringing, is more economical and reduces food-borne illness (Benjaminson et al., 2002). So, ongoing experiments on initial stem cells under control conditions to grow small cell tissues. As enriched protein diet is essential for humans that will be provided by cultured meat and conventional meat cannot fulfill these requirements.

Driving Factors behind the Growth of Lab-Grown Meat

In 2013 Lab-grown meat was first introduced, but did not receive global commercial approval until 2020 when Singapore became the first country to approve the sale and utilization of lab-grown chicken meat. Key factors driving its development include ethical behavior and animal welfare, consumer health, the safety of food, and environmental sustainability. The introduction of lab-grown meat aims to support a sustainable food supply, especially during periods of booming population and global crises, like pandemics (Warner, 2019; Chong et al., 2022).

Advantages

1. Increased Meat Production: Addresses the growing demand for meat.
2. Customizable Nutrition: Can be developed as a functional food with a tailored nutrient profile to meet dietary needs.
3. Ethical Benefits:
   - Reduces animal sacrifice and cruelty.
4. Environmental Benefits:
   - Lowers greenhouse gas emissions and production of ammonia from farming livestock.
   - Reduces the carbon footprint of animal husbandry.
5. Food Safety and Public Health:
   - Reduces the risk of foodborne illnesses due to the absence of antibiotics.
   - Lowers the risk of zoonotic disease transmission.

Challenges

1. High Production Costs: Currently expensive compared to conventional meat.
2. Environmental Concerns: May still produce significant levels of carbon dioxide.
3. Health Risks: Potential unknown health effects, such as the risk of cell line deregulation leading to cancerous cells.
4. Cultural and Religious Barriers:
   - Conflicts with dietary laws, such as Halal requirements in Islam and prohibitions against beef and pork in Hinduism.
5. Technological Limitations:
   - Limited production quantities.
   - Dependence on animal serum for culture medium, making it not entirely slaughter-free.
6. Consumer Acceptance:
   - Taste and texture do not yet fully replicate conventional meat.

Environmental Sustainability

Excessive meat consumption has significant environmental consequences. The main contributor to global warming is the meat industry, as it requires to fulfil livestock needs substantial resources, like soil and water, while also generating large amounts of (GHG) greenhouse gas emissions (Ben-Arye & Levenberg, 2019; Ben-Arye et al., 2020). 95% of greenhouse gas (GHG) emissions come from livestock farming, which includes methane, carbon dioxide, and nitrous oxide. Activities such as fertilizer application, manure management, land grazing, and enteric fermentation in animals are the reason for these emissions and implemented significantly to degradation and environmental pollution (González et al., 2020).

Aggressive livestock farming is the main cause of air, water and land pollution. High concentrations of environmental ammonia (NH_3) are released by livestock farming, which arises from the breakdown of uric acid in animal dung and urine through urease activity. Air and water pollution are the results of these emissions and can have harmful environmental effects (Jacobsen et al., 2019). In livestock manure management ammonia is a common odor-causing substance, and in composting areas concentrations reach up to 4100ppm. In present challenges for waste management in livestock farming these high ammonia levels can contribute to air pollution (Wang et al., 2021).

Although animal products account for fewer than 20% of the global supply of food energy, their production has disproportionately negative impacts on natural resources. Greenhouse Gas Emissions: Food production and consumption are responsible for approx. 13.7 million metric tons of CO_2 commensurate with, contributing around 26% of all human-induced greenhouse gas emissions. Terrestrial Acidification: The food supply chain contributes to 32% of global terrestrial acidification, impacting soil health. Eutrophication: It accounts for about 78% of eutrophication, which disrupts aquatic ecosystems by promoting excessive nutrient accumulation (Searchinger et al., 2018). Deforestation for livestock pastures and animal feed production is a major environmental issue, particularly in regions like South America. Countries such as Brazil, with its extensive tropical forests, have experienced significant deforestation, where large areas are cleared to create pastures for livestock and soybean fields used for animal feed. This practice contributes to biodiversity loss, carbon emissions, and disruption of ecosystems (Nepstad et al., 2014).

Cultured Meat

Under controlled laboratory conditions lab-grown meat is created completely by using animal cell culture methods. This process combines bioengineering, tissue engineering, biological chemistry, and techniques of chemical and bioprocess engineering (Ben-Arye et al., 2020). (Figure 1). Cells, signals, and scaffolds are three key components required for tissue engineering. First of all, select the most suitable type of cell and it is crucial as a starting point. Next, choose a biocompatible tissue scaffold to provide structural support that will enable the cells to grow and transform properly. Finally, at the last step it is essential to supply the cells with appropriate nutrients and signaling molecules to make sure the proper growth and development of the cell (Hamdy, 2023; Santos et al., 2023). The making of the first hamburger from lab-based meat marked a significant turning point in the historical events of the food industry, igniting the development of this innovative technology in the years that followed in the future. Besides this, meat production was entirely dependent on traditional animal husbandry, a system that not only consumed natural resources at unsustainable rates but also contributed to some of the planet's most crucial environmental challenges.

To expand the lab base meat many startups and research teams around the world are working today, aiming to make this technology widely accessible to consumers. The majority of these efforts are carried out in the United States and the (EU) European Union (Rubio et al., 2020). In late 2020, the Singapore Food Agency (SFA) made history by granting regulatory approval to Eat Just Inc, allowing the inauguration to sell lab-base chicken meat. This allows the first time a government authorized to commercialize the lab-grown meat. Firstly, the product was sold in the restaurant for around $23 USD. By contrast, the very first lab-grown beef burger, created in 2013 by the Dutch startup Mosa Meat, came with a production cost of approximately $330,000 USD (Morais-da-Silva et al., 2022). Brazil, a leading global producer and exporter of meat, is now home to research groups conducting pioneering studies on cultured chicken meat. These efforts aim to include sensory and nutritional analyses, which are anticipated to be completed by 2024 (da Silva & Conte-Junior, 2024). To achieve a high-quality result in lab-grown meat, advanced technology is essential at every stage of the production process.

Stem Cells

To make lab-grown meat, scientists discovered different stem cells. Researchers first discovered Myoblast or satellite cells. Adult stem cells from tissue play a crucial role in helping muscles repair after an injury. However, maintaining their growth potential in cell culture has proven to be challenging (Mauro, 1961; Collins et al., 2007). When cultured in large quantities, satellite cells readily differentiate into myotubes and additionally developed muscle fibres. This characteristic makes them an ideal cell origin for constructing tissues of muscle. Recent findings on mature satellite cells reveal that few are particularly efficient at the repair and regeneration, further highlighting their potential in tissue engineering (Pallafacchina et al., 2013; Kaczmarek et al., 2021).

Stem cells exhibit a range of characteristics, from totipotency (capable of developing into a complete organism) to monopotent (having power in one way only), in a hierarchical order. Selecting the appropriate cell type is critical for producing lab-based meat through in vitro cell culture. Additionally, replicating the in vivo environment, known as the stem cell niche, is crucial for maintaining cells in vitro. Typically, the physical substrate that supports cells is replaced by scaffolds, while body fluids supplying nutrients are substituted with culture media (Tewary et al., 2018). Somatic muscle is composed of various types of cells. Muscle fibres are formed when muscle cells from embryos and young animals divide, transform, and fuse with each other, creating large cells that contain multiple nuclei. Attempt to stimulate the growth of more muscle fibers often fail because cell nuclei in most of the muscles remain lifeless and do not divide. While cells of embryonic stem can grow and differentiate into various cell types, this process is challenging to induce, limiting the number of cells that can be harvested. It is unclear whether embryonic stem cells can continue to grow rapidly and become somatic muscle cells or if they will differentiate into other cell types. Therefore, the most promising cells for lab-based meat production are expected to be those derived from the muscles of embryos or young animals (McFarland et al., 1991).

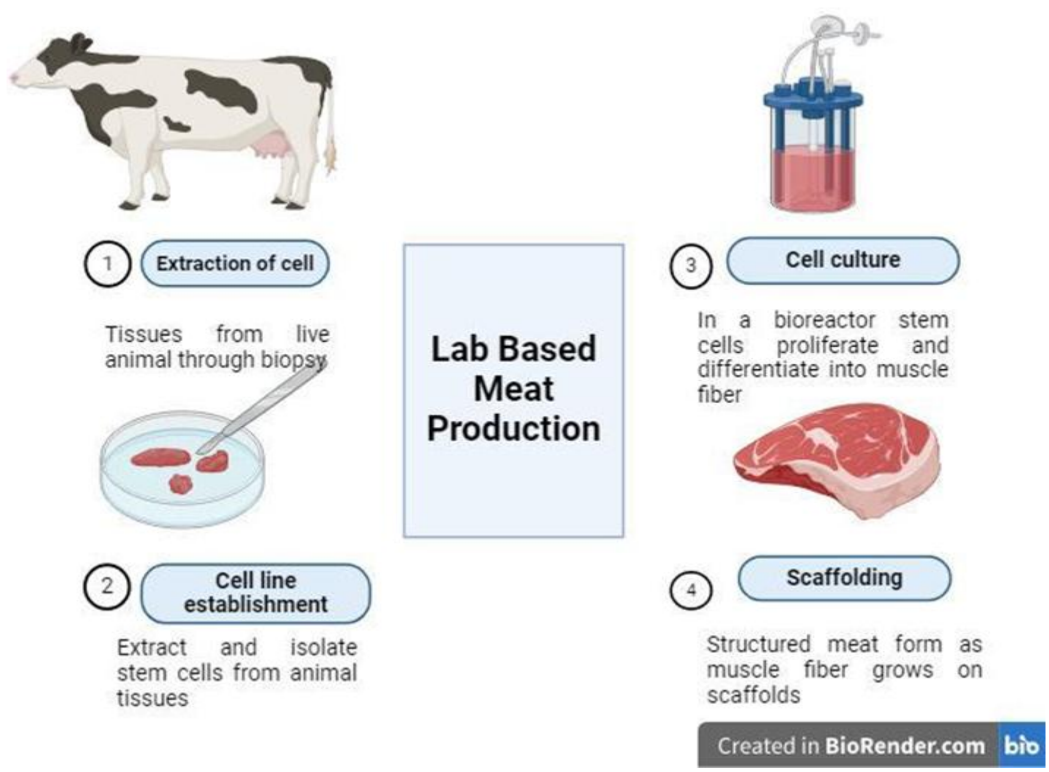

Fig. 1: Structure for lab-based meat production

Cell Culture

Cell development normally occurs in cell culture media including (DMEM) Dulbecco's Modified Eagle Medium and (MEM) Minimal Essential Medium. Fetal bovine serum (FBS) and/or horse serum are used to boost these media, which provide essential growth factors that support and encourage the growth of cell. To support cell growth, providing additional growth factors that aid in the growth and differentiation of cells other cell cultures have also incorporated chicken embryos as a natural essence (Stephens et al., 2018; Srutee et al., 2022). To manage metabolic processes and assist the differentiation of muscle cells, hormones like insulin and dexamethasone are commonly added to the cell culture media. The formation of muscle tissue and the development of cells are guided and supported by these hormones. To maintain the optimal pH of the cell culture medium HEPES and bicarbonates buffering agents are crucial (Tyagi & Mani, 2023). To ensuring cell viability and function it is important, as changes in pH can negatively impact cell growth and activity.

To simulate the intrinsic environment of cells, cell culture medium solution was designed carefully due to its complexity. To assist the growth of cells and their functions it supplies essential nourishment, growth factors, and other components needed. On this basis for the production of cultured meat, the medium is specifically adapted to support the growth and differentiation of muscle cells, facilitating the growth of the tissue of muscle that closely looks like natural meat (Lee et al., 2023).

Table 1: Lab Based Meat Challenges in Industry

Limitations in Technology	Laws and Legislations	Consumer Acceptance
● Cell line	● Food Labeling	● Food Neophobia
● Media of cell culture	● Risk Assessment	● Economic Anxieties
● Scaffold and Biomaterials		● Socioeconomic in Meat Consumption
● Bireactors		

Scaffolds and Biomaterials

In the industry of lab-based meat, evolutions in scaffold technology are crucial to copy the 3D structure and feel of real meat. The formation of efficacious scaffolds remains a significant technological challenge in lab-grown meat production. Current scaffolds used in muscle tissue engineering can only achieve thicknesses of a few mm (around 3 mm) and often exhibit derelict mechanical properties, which limit the attachment of cells and multiplication (Stephens et al., 2018; Seah et al., 2022). In in vitro (artificial insemination) culture, scaffolds serve as biomimetic materials that replicate the in vivo (in living organisms) stem cell niches by giving a 3D clammy surface (Figure 2). This helps the morphogenesis of stem cells and the maturation of tissues, unlike the 2D cultures using traditional tissue culture plates.

To arrange artificial tissues from stem cells in vitro hydrogel and porous scaffolds are commonly used. Hydrogel is a hydrophilic polymer and is particularly effective for generating self-arranging artificial tissues or organoids, from stem cells. These scaffolds enable stem cells to follow their revolutionary programs, facilitating in vitro morphogenesis by copying in vivo micro-environments (Ostrovidov et al., 2014; Hofer & Lutolf, 2021). It's essential to adhere to specific guidelines for scaffold use when producing lab-grown meat. Scaffolds must be biocompatible, meaning they are safe for the body and capable of degrading over time. They should have appropriate strength and structure to support cell growth. If we compare 2D and 3D culture systems, 3D fat production enhances both the effectiveness and the degree of discrimination. While the 2D culture commonly results in lipid accumulation of multi-layer. Large, unilocular lipid droplets can be produced in the 3D system, which are features of mature adipocytes. Additionally, 3D culture induction promotes a higher discrimination rate compared to traditional monolayer cultures (Ma et al., 2018; Dohmen et al., 2022).

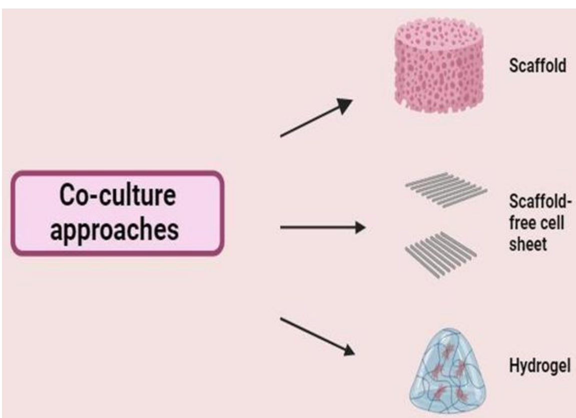

Fig. 2: 3D culture technique for the cultured meat process

Scaffolds must have the correct size and texture, adapted to the desired function. Based on the specific requirements for muscle tissue formation of features of the scaffold should be carefully selected (Levi et al., 2022). On other hand, plant-based protein scaffolds have gathered significant scientific interest due to their huge accessibility, lowness, biological acceptance, and considerable nutritional value. Moreover, they offer benefits for environmental sustainability and animal welfare. However, one limitation of using plant-based scaffolds is their relatively poor mechanical properties and their ability to carry the growth and effective development of muscle tissue can be affected by this. This issue can be resolved through several approaches, such as using processes like chemical, physical, or enzymatic crosslinking, or by incorporating materials with better mechanical properties. The most commonly used plant-derived proteins for scaffold production are zein and soy proteins (Ben-Arye & Levenberg, 2019).

Consumer Perception

An innovative alternative to traditional meat is lab-grown meat, which raises the question of how will consumer react or what will be their perception. Industry plays an important role in consumer acceptance because of consumer perceptions associated with food technology and consumer's trust in the industry (Siegrist & Hartmann, 2020). Diseases that spread from animals to humans and that are resistant to antibiotics are also concerns of consumers so the best possible option is cultured meat which also fulfills demand for meat in the world (Tuomisto, 2019; Tuomisto, 2021).

(Table 1) Lab-grown meat makes sure it is safe to eat and good quality that is checked by the digital systems which prevent bacteria to enter in the food when prepared. To check if meat tastes good and fulfills nutrients' requirements after its preparation we need to use a control system (Bhat & Fayaz, 2011).

Conclusion

Lab-grown meat from stem cells is a revolutionary change in the meat industry in the way we produce meat and consume it. The demand for sustainable and ethical alternatives to traditional meat production becomes necessary as the globally, population continues to grow and intensify environmental challenges. The advancements in cell culture techniques, stem cell research, and bioreactor technology have brought cultured meat closer to commercial viability, offering the potential to reduce usage of land, consumption of water, and emissions of greenhouse gas but also addressing animal welfare concerns. But with that there are still significant challenges to overcome, such as scaling production, reducing costs, and navigating regulatory landscapes and consumer acceptance. However, the rapid pace of innovation in this field, alongside growing consumer acceptance and investment, signals a bright future for lab-grown meat. As technology evolves and new solutions emerge, cultured meat could play a crucial role in ensuring food security, improving sustainability, and reshaping the global food system. The next few years will be pivotal in determining how this technology integrates into our diets, ultimately transforming the way we think about meat and its place in the world.

References

Ben-Arye, T., & Levenberg, S. (2019). Tissue engineering for clean meat production. *Frontiers in Sustainable Food Systems, 3*, 46.

Ben-Arye, T., Shandalov, Y., Ben-Shaul, S., Landau, S., Zagury, Y., Ianovici, I., & Levenberg, S. (2020). Textured soy protein scaffolds enable the generation of three-dimensional bovine skeletal muscle tissue for cell-based meat. *Nature Food, 1*(4), 210-220.

Benjaminson, M. A., Gilchriest, J. A., & Lorenz, M. J. A. A. (2002). In vitro edible muscle protein production system (MPPS): Stage 1, fish. *Acta Astronautica, 51*(12), 879-889.

Bhat, Z. F., & Fayaz, H. (2011). Prospectus of cultured meat—advancing meat alternatives. *Journal of Food Science and Technology, 48*, 125-140.

Chong, M., Leung, A. K. Y., & Lua, V. (2022). A cross-country investigation of social image motivation and acceptance of lab-grown meat in Singapore and the United States. *Appetite, 173*, 105990.

Churchill, W. S. (2016). *Thoughts and adventures*. Rosetta Books.

Collins, C. A., Zammit, P. S., Ruiz, A. P., Morgan, J. E., & Partridge, T. A. (2007). A population of myogenic stem cells that survives skeletal muscle aging. *Stem Cells, 25*(4), 885-894.

da Silva, B. D., & Conte-Junior, C. A. (2024). Perspectives on cultured meat in countries with economies dependent on animal production: a review of potential challenges and opportunities. *Trends in Food Science & Technology, 149*, 104551.

Dohmen, R. G., Hubalek, S., Melke, J., Messmer, T., Cantoni, F., Mei, A., & Flack, J. E. (2022). Muscle-derived fibro-adipogenic progenitor cells for production of cultured bovine adipose tissue. *NPJ Science of Food, 6*(1), 6.

Eibl, R., Senn, Y., Gubser, G., Jossen, V., Van Den Bos, C., & Eibl, D. (2021). Cellular agriculture: opportunities and challenges. *Annual Review of Food Science and Technology, 12*(1), 51-73.

González, N., Marquès, M., Nadal, M., & Domingo, J. L. (2020). Meat consumption: Which are the current global risks? A review of recent (2010–2020) evidences. *Food Research International, 137*, 109341.

Hamdy, T. M. (2023). Dental biomaterial scaffolds in tooth tissue engineering: a review. *Current Oral Health Reports, 10*(1), 14-21.

Heinz, G., & Hautzinger, P. (2007). *Meat processing technology for small-to medium-scale producers*. FAO, Bangkok, Thailand.

Hofer, M., & Lutolf, M. P. (2021). Engineering organoids. *Nature Reviews Materials, 6*(5), 402-420.

Jacobsen, B. H., Latacz-Lohmann, U., Luesink, H., Michels, R., & Ståhl, L. (2019). Costs of regulating ammonia emissions from livestock farms near Natura 2000 areas-analyses of case farms from Germany, Netherlands and Denmark. *Journal of Environmental Management, 246*, 897-908.

Kaczmarek, A., Kaczmarek, M., Ciałowicz, M., Clemente, F. M., Wolański, P., Badicu, G., & Murawska-Ciałowicz, E. (2021). The role of satellite cells in skeletal muscle regeneration—the effect of exercise and age. *Biology, 10*(10), 1056.

Lee, D. Y., Lee, S. Y., Jung, J. W., Kim, J. H., Oh, D. H., Kim, H. W., & Hur, S. J. (2023). Review of technology and materials for the development of cultured meat. *Critical Reviews in Food Science and Nutrition, 63*(27), 8591-8615.

Levi, S., Yen, F. C., Baruch, L., & Machluf, M. (2022). Scaffolding technologies for the engineering of cultured meat: Towards a safe, sustainable, and scalable production. *Trends in Food Science & Technology, 126*, 13-25.

Ma, Y. N., Wang, B., Wang, Z. X., Gomez, N. A., Zhu, M. J., & Du, M. (2018). Three-dimensional spheroid culture of adipose stromal vascular cells for studying adipogenesis in beef cattle. *Animal, 12*(10), 2123-2129.

Mauro, A. (1961). Satellite cell of skeletal muscle fibers. *The Journal of Biophysical and Biochemical Cytology, 9*(2), 493.

McFarland, D. C., Pesall, J. E., Norberg, J. M., & Dvoracek, M. A. (1991). Proliferation of the turkey myogenic satellite cell in a serum-free medium. *Comparative Biochemistry and Physiology Part A: Physiology, 99*(1-2), 163-167.

Morais-da-Silva, R. L., Reis, G. G., Sanctorum, H., & Molento, C. F. M. (2022). The social impacts of a transition from conventional to cultivated and plant-based meats: evidence from Brazil. *Food Policy, 111*, 102337.

Nepstad, D., McGrath, D., Stickler, C., Alencar, A., Azevedo, A., Swette, B., & Hess, L. (2014). Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. *Science, 344*(6188), 1118-1123.

Ostrovidov, S., Hosseini, V., Ahadian, S., Fujie, T., Parthiban, S. P., Ramalingam, M., & Khademhosseini, A. (2014). Skeletal muscle tissue engineering: methods to form skeletal myotubes and their applications. *Tissue Engineering Part B: Reviews, 20*(5), 403-436.

Pallafacchina, G., Blaauw, B., & Schiaffino, S. (2013). Role of satellite cells in muscle growth and maintenance of muscle mass. *Nutrition, Metabolism and Cardiovascular Diseases, 23*, S12-S18.

Rischer, H., Szilvay, G. R., & Oksman-Caldentey, K. M. (2020). Cellular agriculture—industrial biotechnology for food and materials. *Current Opinion in Biotechnology, 61*, 128-134.

Rubio, N. R., Xiang, N., & Kaplan, D. L. (2020). Plant-based and cell-based approaches to meat production. *Nature Communications, 11*(1), 1-11.

Santos, A. C. A., Camarena, D. E. M., Roncoli Reigado, G., Chambergo, F. S., Nunes, V. A., Trindade, M. A., & Stuchi Maria-Engler, S. (2023). Tissue engineering challenges for cultivated meat to meet the real demand of a global market. *International Journal of Molecular Sciences, 24*(7), 6033.

Seah, J. S. H., Singh, S., Tan, L. P., & Choudhury, D. (2022). Scaffolds for the manufacture of cultured meat. *Critical Reviews in Biotechnology, 42*(2), 311-323.

Searchinger, T. D., Wirsenius, S., Beringer, T., & Dumas, P. (2018). Assessing the efficiency of changes in land use for mitigating climate change. *Nature, 564*(7735), 249-253.

Sharma, S., Thind, S. S., & Kaur, A. (2015). In vitro meat production system: why and how?. *Journal of Food Science and Technology, 52*, 7599-7607.

Siegrist, M., & Hartmann, C. (2020). Consumer acceptance of novel food technologies. *Nature Food, 1*(6), 343-350.

Srutee, R., Sowmya, R. S., & Annapure, U. S. (2022). Clean meat: Techniques for meat production and its upcoming challenges. *Animal Biotechnology, 33*(7), 1721-1729.

Stephens, N., Di Silvio, L., Dunsford, I., Ellis, M., Glencross, A., & Sexton, A. (2018). Bringing cultured meat to market: Technical, socio-political, and regulatory challenges in cellular agriculture. *Trends in Food Science & Technology, 78*, 155-166.

Tewary, M., Shakiba, N., & Zandstra, P. W. (2018). Stem cell bioengineering: building from stem cell biology. *Nature Reviews Genetics, 19*(10), 595-614.

Tuomisto, H. (2021). The eco-friendly burger. *EMBO Reports, 22*(4), e52698.

Tuomisto, H. L. (2019). The eco-friendly burger: could cultured-meat improve the environmental sustainability of meat products? *EMBO Reports, 20*(1), e47395.

Tyagi, S., & Mani, S. (2023). Media and buffer preparation for cell culture. In *Animal Cell Culture: Principles and Practice* (pp. 77-88). Cham: Springer International Publishing.

Wang, Y. C., Han, M. F., Jia, T. P., Hu, X. R., Zhu, H. Q., Tong, Z., & Hsi, H. C. (2021). Emissions, measurement, and control of odor in livestock farms: A review. *Science of the Total Environment, 776*, 145735.

Wang, Y. X., & Rudnicki, M. A. (2012). Satellite cells, the engines of muscle repair. *Nature Reviews Molecular Cell Biology, 13*(2), 127-133.

Warner, R. D. (2019). Analysis of the process and drivers for cellular meat production. *Animal, 13*(12), 3041-3058.

Wyness, L., Weichselbaum, E., O'connor, A., Williams, E. B., Benelam, B., Riley, H., & Stanner, S. (2011). Red meat in the diet: an update. *Nutrition Bulletin, 36*(1), 34-77.