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Abstract

Cultured meat has been gaining popularity as a solution to the increasing problem of food insecurity. Although research on cultured meat started later compared to other alternative meats, the industry is growing rapidly every year, with developed products evaluated as being most similar to conventional meat. Studies on cultured meat production techniques, such as culturing new animal cells and developing medium sera and scaffolds, are being conducted intensively and diversely. However, active in-depth research on the quality characteristics of cultured meat, including studies on the sensory and storage properties that directly influence consumer preferences, is still lacking. Additionally, studies on the combination or ratio of fat cells to muscle cells and on the improvement of microbiota, protein degradation, and fatty acid degradation remain to be conducted. By actively investigating these research topics, we aim to verify the quality and safety of cultured meats, ultimately improving the consumer preference for cultured meat products.

Keywords: Cultured meat, Manufacturing, Nutritional properties, Sensory properties, Storage properties

Introduction

With the recent increase in the global population, per capita gross domestic product (GDP) and meat consumption are steadily increasing (Hong et al., 2021). The continual increase in meat consumption is expected to increase the demand for staple meats, such as beef, pork, and chicken, by an average of 70% by 2050 (Siddiqui et al., 2022A). Increased meat production is essential to meet such demand. However, traditional and conventional livestock farming methods are becoming increasingly inadequate in meeting this demand, owing to the requirements of large quantities of finite resources, such as land, water, and grains (Guan et al., 2021). As a result, this situation is expected to lead to ongoing issues of food insecurity and environmental problems (Goodwin and Shoulders, 2013). Therefore, some people have started to adopt various forms of veganism as a dietary choice. This includes consumers classified as core vegans, trend-setting vegans, trend-following vegans, imperfect vegans, green vegans, and potential vegans (Treich, 2021). Moreover, plant-based proteins, insect proteins, and cultured meat are some of the products that have been researched and developed as alternatives to animal protein (Onwezen et al., 2021).

Cultured meat, also known as lab-grown meat, is the most recently developed alternative protein source. It is produced by in vitro culturing of cells taken from the animal's body (Siddiqui et al., 2022B). Because cultured meat is produced through cell cultivation in bioreactors, it has fewer ethical, religious, and environmental constraints than meats produced by traditional livestock farming (Bryant, 2020). Therefore, the commercialization of cultured meat in the protein market is anticipated to have a promising outlook and offers advantages for introducing meats that are difficult to produce through traditional farming methods, or are not commonly available, such as wild game (Lee et al., 2023). This development broadens the diversity of food options for consumers. Furthermore, meat cultivation provides the potential to enhance nutritional content and incorporate additives with various biofunctionalities, such as antioxidants and anticancer and anti-inflammatory molecules, surpassing the benefits of consuming conventional meat (Nobre, 2022).

However, globally integrated industrial regulations remain incomplete, and scientific research on this matter is also lacking. This suggests that cultured meat may be advantageous in helping to manage consumer health. Despite the fact that the cultured meat industry is advancing through various research and product development efforts, further validation of the products is required, particularly in terms of tissue texture and food safety (Ramani et al., 2021).

Manufacturing of cultured meat

Donor selection

Donor selection is the most fundamental aspect of the production process, involving considerations such as the breed, sex, and age of the animal and the specific body part from which the cells are sourced (Stephens et al., 2018). As shown in Table 1, cultured meat is being produced from cells sourced from various types of animals. Currently, a significant number of commercialized products derived from this process have been developed and are available to consumers (Lee et al., 2022A). For these products, the cells are primarily sourced (in descending order of usage) from cattle (25%), poultry (22%), seafood (19%), pigs (19%), and other animals (15%) (Choudhury et al., 2020). Cattle and poultry are predominantly used for research purposes and most of those researches are targeted at religious consumers (Bryant, 2020).

Also, many consumers and scientists commonly know that cultured meat has high advantages for religious reasons and the standard of cell selection is influenced by its reasons. However, for example in the Islamic community, the main point of choosing meat is “Does the meat (cultured meat) produced follow the halal status?” and this point shows that cultured meat isn’t always suitable for religious people (Chriki and Hocquette, 2020). Furthermore, Siddiqui et al. (2022B) reported that socially conservative consumers expressed negative reactions towards cultured meat, and some religious communities, such as Hindus, expressed vegetarianism is regarded as superior to meat eating. These discussions bring the new research development of cell selection and collection techniques from animal bodies and many new studies have to be started.

Once the livestock breed is selected, the next step involves selecting factors such as sex, age, and specific parts of the animal. This decision is dictated by the quality of the satellite cells in the collected muscle tissue (Skrivergaard et al., 2023), which is determined by assessing factors such as their yield and differentiation capacity (Arshad et al., 2017). This assessment is conducted to select the most suitable tissue for meat cultivation. Determining the quality of satellite cells is crucial because the cells play a pivotal role in the regeneration of the muscle tissue that has been damaged through injury (Hong et al., 2021), making them the most critical factor in the cell selection process. Kim et al. (2023A) reported that many factors (such as gender, age, and environment) affect cultured meat production and there are existing unfigured mechanisms that need research. Coles et al. (2015) reported that the breed of origin, live weight at slaughter, and carcass weight affect the collected cell proliferation and this seems that differential gene expression is the main reason for these phenomena.

For these reasons, the final product of cultured meat is affected by the cell donor animal’s genetic characteristics, some researchers are proposing to establish optimized cell models in genetic engineering tools concerning genetically modified organisms (GMOs) (Martins et al., 2023). Also, some researchers found out that cultured meat is more suitable for their Swiss sample compared to GMOs food and this could be a key point for getting balance in the genetic engineering side of cultured meat (Bryant and Barnett, 2020). This describes that many new studies can be excavated in the donor selection part and could be additional scientific data for the traditional meat industry.

Cell isolation

Cell separation is the process by which the satellite cells are efficiently isolated from the muscle tissue (which comprises various cell types, including muscle fibers and stem cells) (Li et al., 2022A). This process ensures that only satellite cells are obtained from the tissue. Typically, after the initial separation through physical and chemical dissociation, secondary separation is performed using methods such as filtration and centrifugation, density gradient centrifugation, and cell separation based on the antigen–antibody reactions of surface markers (Swatler et al., 2020). Two commonly used cell separation methods are fluorescence-activated cell sorting (FACS) and magnetic-activated cell sorting (MACS) (Table 2).

FACS utilizes antigen–antibody reactions to recognize surface markers on cells as antigens, which have been pre-labeled with fluorescent substances to facilitate the cell sorting process. A flow cytometer is used to separate the cells, allowing for the precise analysis of their size and internal structure (Kim et al., 2022A). Furthermore, the integration of FACS with sequencing, known as FACSeq, proves to be highly effective. This approach enables the detailed exploration of individual cell physiology, facilitating the identification based on factors such as relative nucleic acid contents and cell membrane integrity (Dridi et al., 2023). Recently, owing to the meticulous nature of the FACS method, certain researchers have devised a FACS strategy specifically for purifying adipose progenitor cell (APC). Subsequently, they demonstrated that the purified APC exhibited a notable capacity for proliferation and adipogenic differentiation (Song et al., 2022).

Similarly, MACS relies on antigen–antibody reactions, but antibodies with magnetic properties are used instead to react with antigens on the cell surface. Cells with attached antibodies are then separated using a magnet. This method facilitates rapid cell separation and high cell viability (Choi et al., 2020). Hence, MACS is considered less disruptive in the separation process compared to FACS, making it a more suitable choice for large-scale expansion (Kim et al., 2023B). While FACS incurs significant costs for both entry and maintenance and exhibits slow speed, hindering high-throughput sample handling, Bead-based MACS is a solution to these issues. Nonetheless, magnetic-based approaches grapple with challenges such as low specificity (stemming from the use of a single antibody type) and difficulties in scaling up samples due to the intricate relationship between magnetic field strength and distance (McNaughton et al., 2022).

Taking advantage of the strengths of both FACS and MACS, a hybrid approach that combines these two techniques for cell separation is being widely used in research pertaining to cultured meat production (Guan et al., 2022). In combining two techniques, the strengths of FACS, known for its multiple labeling and sorting capabilities, and MACS, appreciated for high throughput and quick sorting times. Kang et al. (2021) reported they developed an Immunomagnetic Microfluidic Integrated System (IM-MIS) that achieves high yield, high throughput, and minimal loss based on the differentiated cell phenotype.

With the ongoing advancements in these technologies, there is an anticipation that cell separation technology will stabilize, facilitating swift industrial progress in the field of cell sorting.

Cell culturing

Cell culturing primarily involves the use of proliferation methods to increase the number of selected cells (Figure 1). Various substances, such as basal culture medium, serum, growth factors, and antibiotics, are used to provide the necessary conditions for cell regeneration and maturation during this process (Siddiqui et al., 2022B). Basic culture media, such as Dulbecco's modified Eagle's medium (DMEM), contain essential nutrients to support and maintain the growth and health of the cells while exponentially increasing their numbers. DMEM offers several advantages, such as commercial availability and a bio-mimicking environment enriched with ingredients like amino acids and vitamins. Consequently, DMEM addresses challenges associated with time-consuming preparation, as well as various issues related to precipitation and storage (Bayrak et al., 2020).

Any deficiencies in the basic medium are supplemented with additives, such as a specific serum, growth factors, and antibiotics (Zhang et al., 2020). Specifically, animal-derived sera, such as fetal bovine serum

(FBS), are crucial for cell cultures because they are highly effective in promoting cell proliferation (Post et al., 2020). FBS, naturally tailored for the prenatal development of unborn calves, boasts an extensive array of nutrients, growth factors, and adhesion factors with minimal antibody content (van der Valk, 2022). Its historical preference stems from its relatively low cost and widespread availability, making FBS the primary choice for supplementing nearly all eukaryotic cell culture media. However, demand for alternatives to sera is growing, owing to the ethical concerns and high costs associated with their use. In recent years, various blood-free additives, such as B-27^{TM} and Xerum Free^{TM}, have been developed to replace FBS (Guan et al., 2021). These products aim to minimize animal sacrifice and reduce the cost of cultured meat production. Furthermore, to alleviate concerns regarding the consumption of antibiotics and anti-inflammatory agents in the final cultured meat products, some producers have opted for methods that do not use these unwanted bioactive molecules. However, this approach requires delicate culture control, as it can lead to a sharp decrease in cell viability (Piochi et al., 2022).

Microcarriers, an optional material for cell culturing, are formed into beads and have been established as an expanded growth surface to support the differentiation and proliferation of various types of cultured cells (Norris et al., 2022). And there are edible, non-edible, and degradable microcarriers exist, among those kinds, edible microcarrier is most preferred and it is classified into polysaccharides, lipids, polypeptides, and composites/synthetics (Bodiou and Post, 2020). The importance of edible microcarriers is to reduce the final cost of cultured meat products by increasing cell harvest yield (Zernov et al., 2022).

The most critical environmental factor in cell culturing is temperature, as it is essential for cell culturing. Mass cell culturing is predominantly carried out in bioreactors, where optimal cell culture is conducted at a temperature of 37℃, mimicking the human body, and supplied with oxygen (Garrison et al., 2022). Guan et al. (2022) reported that mildly elevated temperatures (39℃) and mechanical stimulation are among the environmental cues that have been proven to boost both myogenic differentiation and hypertrophy. Some environmental cues like mild high temperature (39℃) and mechanical movement have also been demonstrated to enhance myogenic differentiation and hypertrophy (Guan et al., 2022). Consequently, while inducing heat stress through elevated culture temperatures may not independently suffice for cell growth and differentiation, it can effectively promote growth factor-mediated cell proliferation and differentiation (Oh et al., 2023).

Taking these aspects into consideration, both in cell culture and collection, it becomes imperative to align with the ethical consumption tendencies of consumers. Simultaneously, there is a continuous need to explore avenues that provide industrial economic advantages.

Cell structuring

In cell structuring, the main point is to stabilize the differentiation of muscle cells. It is also called subsequent hypertrophy and this is the mix of biochemical and mechanical stimuli (Post, 2012). A scaffold structure is necessary for organizing the cultured cells into tissues. To reproduce all important features of conventional meat, the set of requirements for biomaterials used to produce cultured meat is highly specific (Wollschlaeger et al., 2022). The material should be edible, sustainable, widely available, animal-free, non-toxic, cheap, processable, and ideally have none or only a mild taste.

Animal-derived scaffolds, which are primarily composed of collagen, have the advantage of providing minimal heterogeneity during cell cultivation. Furthermore, they contribute to the texture and flavor of the final product, aiding in replicating the characteristics of conventional meat (Seah et al., 2022). Collagen gels or collagen–Matrigel complexes are commonly used because they enhance protein production (Figure 4) (Post, 2012). Collagen stands out as a well-established material for cell adherent coatings in tissue engineering. Considering that HC peptides share the identical amino acid sequence with collagen and retain cell-binding capability even after collagen denaturation into gelatin, it is reasonable to anticipate robust cell adhesion on hydrolyzed collagen surfaces (Koranne et al., 2022).

Plant-based scaffolds, which are existing plant structures onto which the cultured cells can be attached, offer the simplest means to achieving cellular myogenesis. Additionally, they allow for the consumption of nutrients naturally present in plants, providing an added advantage (Levi et al., 2022). Decellularized spinach is a representative plant-based scaffold that shows high cell adhesion and survival rate and forms suitable cost on the industrial side (Jones et al., 2021). To reproduce the structure of muscle tissues in decellularized spinach scaffolds, the critical factors include the precise composition of the tissue, the arrangement of cells within the scaffold, and the influence of surface topography and cell origin, which may vary based on plant species and leaf position (Rao et al., 2023). However, plant-based scaffolds, which may include polysaccharides such as cellulose, alginate, and hyaluronic acid, carry the risk of inducing allergies (Djisalov et al., 2021), rendering them less suitable for consumption by vulnerable consumers.

Recently, interest in the use of 3D printing technology has been growing, and research studies on the use of 3D printers to produce scaffolds and to directly create cultured meat in the shape of conventional meat are underway (Ramani et al., 2021). In 3D bioprinter, the nozzle size, extrusion pressure, and source of filler highly affect the final products of cultured meat (Djisalov et al., 2021). The main strength of 3D printing technology is the creation of free forms, allowing researchers to realize the desired shape with a high realization rate and freely adjust the type and proportion of the structure (Li et al., 2021). Also enhancing tissue distribution of macromolecules and cells, this technique contributes to producing final products with improved organoleptic properties, offering precise deposition of cells, micronutrients, technological aids, and biomaterials in predefined locations and shapes, presenting advantages over alternative biofabrication methods (Barbosa et al., 2023).

While these aspects greatly aid in the differentiation of cells cultured on the scaffold into muscle, it seems essential to establish cell classification and safety verification methods that align with the scaffold's characteristics.

Quality properties of cultured meat

Nutritional properties

Various technological development studies have been conducted aiming to achieve comparable nutritional components, such as protein, essential amino acids, vitamins, and mineral content, in cultured meat compared to conventional meat, from a nutritional perspective (Fraeye et al., 2020). The nutritional quality of cultured meat is influenced by the basic culture medium, serum, growth factors, and other nutrients used in the cell culture. Various studies are underway to investigate the nutritional composition and content of the products (Chriki and Hocquette, 2020). As of now, the protein content (the main reason why people eat meats) of cultured meat has not been quantified; however, morphological observations suggest similarities to traditional meat in terms of cytoskeletal proteins, with current research focusing on optimizing the nutrient content of the growth medium to promote the development of cells with higher protein content (Broucke et al., 2023). So huge differences appear in other nutrient contents except protein contents between traditional meat and cultured meat.

The type and content of fat in cultured cells can be adjusted according to the manufacturer's preference or purpose, and, like muscle cells, they must undergo a separate differentiation process during cultivation (Fish et al., 2020). Fraeye et al. (2020) reported that the nature of the production process rendered regulation of the fat composition of cultured meats possible, thus allowing for the development of healthier products through adjustments of the essential fatty acid, polyunsaturated fatty acid, and trans-unsaturated fatty acid ratios and calorie content. Accumulating as storage compounds in animal muscles, conventional meat is a nutritionally dense food rich in high-quality proteins, as well as a diverse array of vitamins and minerals (Singh et al., 2022). Meat blood is abundant in various nutrients, particularly minerals like calcium, iron, magnesium, potassium, and sodium (Lee et al., 2022B). Therefore, consuming meat not only provides essential nutrients directly but also includes minerals that are present in the blood.

However, in cultured meat, nutrient contents such as vitamins, minerals, etc. are affected by serum. The composition and quantity of serum used can vary depending on the donor’s biological information, diet, and lifestyle (Lee et al., 2022C). Therefore, even the same type of serum can have differences in components and amount. Kadim et al. (2015) reported that in cultured meat, the essential amino acids, minerals, vitamins, and bioactive compounds provided by the basic culture medium, serum, and other nutrients used during cell culture were similar to or even exceeded those in conventional meat, demonstrating the nutritional advantages of meat cultivation. Currently, Ultroser G serves as a commercially available serum-free growth medium, acting as a substitute for fetal bovine serum. It encompasses all the essential nutrients required for eukaryotic cell growth, including growth factors, binding proteins, adhesion factors, vitamins, hormones, and mineral trace elements (Jairath et al., 2021).

Therefore, cultured meat maintains its nutritional quality and can even contain enhanced contents of nutrients such as essential amino acids and fatty acids that may be lacking in conventional meat. The meat culturing process, thus, allows for the production of products with high nutritional value.

Textural properties

The latest research on textural properties has exposed suboptimal structuring and texture attributes in manufactured cultured meat (Starowicz et al., 2022). Notably, non-instrumental studies profiling texture has centered on sensory characteristics, including hardness, springiness, and chewiness (Yuliarti et al., 2021). Li et al. (2022B) reported that meat cultured on edible 3D chitosan–sodium alginate–collagen/gelatin scaffolds had similar textural characteristics (e.g., chewiness, springiness, and resilience) as those of conventional meat of the same weight, a finding they attributed to the comparable fibrous characteristics of both products. Furthermore, in a study on cultured meat production using pig muscle stem cells, Zhu et al. (2022) found that the addition of L-ascorbic acid 2-phosphate (Asc-2P) during the cell culture phase led to increased expression of the myosin heavy chain protein and differentiation genes, which resulted in enhancement of the tissue texture. Moreover, in their research on cultured meat using smooth muscle cells, Zheng et al. (2021) observed that the texture of the final product was significantly influenced by the collagen content. They found that the co-culturing of smooth muscle cells with hydrogel and formation of a network structure enhanced the texture of cultured meat. This indicates that, aside from the characteristics of the cultured cells themselves, the type of scaffold and additives used can also affect the texture of the final product. Toiyama et al. (2020) found that among various scaffold structures, those mimicking the striped texture resembling muscle architecture promote myotube formation.

Also, some scaffolds can undergo breakdown and reconstruction by cells, in general, maintaining the structure and mechanical properties of the scaffold has a significant impact on the texture of cultured meat (Langelaan et al., 2010). In light of this, there is a trend in developing scaffolds using edible materials such as alginate, gelatin, collagen, and starch, taking advantage of the characteristics of the scaffold. Among various scaffolds, animal-derived ones are suggested to more closely mimic the traditional texture of meat compared to plant-based scaffolds (Levi et al., 2022). Paredes et al. (2022) compared the textural properties of commercially available conventional sausages and sausages made from cultured meat and found that the hardness, cohesiveness, springiness, chewiness, and gumminess of the two products were similar. This finding suggests that cultured meat products are similar to conventional meat products in terms of textural quality, highlighting the potential for future expansion into the development of cultured meat-based products. However, in the case of cultured meat with a meat-like structure rather than a processed meat form, currently available products for commercial sale have generally received lower consumer evaluations compared to traditional meat (Kim et al., 2022B).

It is particularly suggested that ongoing efforts are needed for further improvement in texture, especially in terms of consistency.

Sensory properties

Intrinsic qualities such as taste, texture, smell, and nutritional value constitute the importance of meat. These essential attributes play a critical role in influencing consumers' choices when it comes to purchasing and consuming meat (Rombach et al., 2022). Furthermore, sensory properties are more treated as main factors than price, health function, and convenience, and if the sensory properties are not well possessed, consumer rejection rapidly increases (Pakseresht et al., 2022). The lipid oxidation products of conventional meat interact with the products of the Maillard reaction, creating a complex flavor profile that contributes to the meat color and taste (Chen et al., 2022). Therefore, for the flavor of conventional meat to be replicated in cultured meat, an understanding of how well the product can mimic the taste of fats is needed (Ng and Kurisawa, 2021).

Further research on the mechanisms of flavor compounds is necessary. Broucke et al. (2023) reported various studies that are using different methods to enhance the flavor of cultured meat, including co-culturing adipocyte precursors with muscle cells and adding carotenoids during the cell culture phase, with a focus on flavor precursors. Additionally, Louis et al. (2023) investigated the regulation of the fatty acid composition in adipose-derived stem cells from Wagyu cattle and found that the initial lipid composition can be controlled by adjusting the fatty acids during the cell differentiation process when producing fat cells. This resulted in a fat composition similar to that of conventional meat. These studies indicate that a foundation for replicating the flavor of fats in cultured meat has been established and underscore the need for continued in-depth research specifically focusing on fat cells. Joo et al. (2022) conducted a comparative study of cultured and conventional meats using electronic nose analysis. The researchers observed that traditionally produced meat was superior in terms of flavors such as umami. Also, Rolland et al. (2020) reported that a contrast in taste was evident between the conventional and 'cultured' hamburgers during the sensory evaluation of six attributes, with the 'cultured' hamburger receiving a slightly favorable assessment.

This superiority was attributed to differences in the maturity of muscle fibers, implying that the flavor of the final cultured meat can be influenced, even during the initial cell selection phase of primed cultivation. All the above findings underscore the need for further research on the combinations and ratios of different types of muscle and fat cells. Verbeke et al. (2015) reported that significant challenges lie in advancing both the product and its production process to closely emulate traditional meat, especially concerning sensory characteristics and pricing.

Additionally, challenges involve scaling up the process for enhanced resource efficiency and cost-effectiveness, along with addressing regulatory and intellectual property issues.

Storage properties

Cultured meat is produced in a sterilized environment free of contaminants, making it generally safer than conventionally produced meat, in terms of microbial contamination. However, proper handling, processing, packaging, and storage practices after production need to be maintained (Siddiqui et al., 2022A). Upon introducing cultured meat to the market in the EU, regulations from the Genetically Modified Food and Feed Law have been applied, encompassing areas such as labeling, official control of animal-derived products, and microbiological criteria (Ketelings et al., 2021). Similar to other food production processes, ensuring safety throughout the entire cultured meat production process in the EU requires the implementation of food safety monitoring systems like Hazard Analysis and Critical Control Points (HACCP).

Maintaining the storage stability of cultured meat serves not only the purpose of protecting consumers' health from microorganisms but also aims to prevent changes in the texture characteristics of the final product, which could impact the tissue structure (Rubio et al., 2020). Ong et al. (2023) reported that the microbial composition of the final product is influenced by the indigenous microbial population in the production environment. Therefore, the post-production microbial composition of cultured meat is anticipated to be similar to that of the indigenous microbial population in the production environment. Additionally, in their study on cultured meat with added carotenoids, Stout et al. (2020) found no significant difference in malondialdehyde values between days 0 and 1 before heating of the regular cultured meat samples; however, after heating, approximately two-fold difference was observed in malondialdehyde values between days 0 and 1. This indicates that the storage conditions, form, and method greatly influence the cultured meat after its production.

In particular, an analysis of the factors that lead to significant changes in meat stability after heating is needed, and the implementation of appropriate storage methods is required. Furthermore, Singh et al. (2022) reported that utilizing the fermentation characteristics of organisms such as mushrooms, yeast, and fungi enhances the taste profile of cultured meat and extends its shelf life. This suggests that the use of natural antimicrobials will increase in the future. Considering that cultured meat is primarily generated in a laboratory environment, it can be regarded as less prone to zoonotic diseases than conventional meat products. However, there are knowledge gaps in the current understanding of food safety concerning cultured meat, particularly because the majority of research endeavors are concentrated on optimizing production methods (Hardi and Brightwell, 2021).

Therefore, future research studies should focus on utilizing various additives to enhance the shelf life of cultured meat while simultaneously improving other characteristics, such as flavor, texture, and nutrition.

Summary and future research

With the diversification of consumer preferences and increasing demand for meat, cultured meat is gaining prominence as a future food resource. Various studies have been conducted on cultured meat production, especially in the development of serum alternatives and scaffolding materials. With regard to serum research, the development of artificial or blood-free serum cultivation methods has the potential to reduce the final cost of cultured meat production. Regarding scaffolding materials, the utilization of 3D printing techniques holds promise for enhancing both the speed and quality of cultured meat production. Although there have been extensive studies on the nutritional quality and histological aspects of cultured meats, research on their sensory and storage characteristics remains relatively limited. Considering that these characteristics directly affect consumer preferences, continuous research and development in these areas are warranted. With regard to sensory characteristics, research on the combination and ratio of muscle and fat cells is required to achieve a flavor similar to that of traditional meat. Furthermore, studies on the storage conditions, forms, and packaging methods are required to maintain the freshness and safety of cultured meats and their products. Specifically, studies on hygiene-related aspects (for instance, microbial composition), lipid oxidation, and protein degradation are crucial to demonstrate the practicality of cultured meats. Such research endeavors are expected to contribute greatly to improving consumer preferences for these products in the future. Furthermore, it appears that ongoing research with sample weights similar to actual meat is imperative to enhance industrial relevance and value. In the future of cultured meat, research at the product level, focusing on weights comparable to finished products, should persist to ensure continuous elevation of industrial value and advancement. This task will likely become a focal point for researchers in the field.

Conflict of interest

The authors declare no potential conflicts of interest.

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Author contributions

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Ethics Approval

This article does not require IRB approval because there are no human and animal participants.

References

Arshad MS, Javed M, Sohaib M, Saeed F, Imran A, Amjad Z. 2017. Tissue engineering approaches to develop cultured meat from cells: a mini review. Cogent Food Agric 3:1320814.

Bain PA, Hutchinson RG, Marks AB, Crane MSJ, Schuller KA. 2013. Establishment of a continuous cell line from southern bluefin tuna (Thunnus maccoyii). Aquacult 376:59-63.

Barbosa W, Correia P, Vieira J, Leal I, Rodrigues L, Nery T, Barbosa J, Soares, M. 2023. Trends and technological challenges of 3D bioprinting in cultured meat: technological prospection. Appl Sci 13:12158.

Bayrak Ö, Ghahramanzadeh Asl H, Ak A. 2020. Comparison of SBF and DMEM in terms of electrochemical properties of common metallic biomaterials. Mater Corros 71:209-221.

Bodiou V, Moutsatsou P, Post M J. 2020. Microcarriers for upscaling cultured meat production. Front Nutr 7:10.

Broucke K, Van Pamel E, Van Coillie E, Herman L, Van Royen G. 2023. Cultured meat and challenges ahead: a review on nutritional, technofunctional and sensorial properties, safety and legislation. Meat sci 195:109006.

Bryant CJ. Culture, meat, and cultured meat. 2020. J Anim Sci 98:skaa172.

Bryant C, Barnett J. 2020. Consumer acceptance of cultured meat: an updated review (2018–2020). Appl Scie 10:5201.

Carpenter CE, Rodriguez BT, Cockett NE. 2000. Growth and differentiation of cultured satellite cells from callipyge and normal lambs. Canadian J Anim Sci 80:297-302.

Chen YP, Feng X, Blank I, Liu Y. 2022. Strategies to improve meat-like properties of meat analogs meeting consumers’ expectations. Biomaterials 287:121648.

Choi KH, Kim M, Yoon JW, Jeong J, Ryu M, Jo C, Lee CK. 2020. Purification of pig muscle stem cells using magnetic-activated cell sorting (MACS) based on the expression of cluster of differentiation 29 (CD29). Food Sci Anim Resour 40:852.

Choi KH, Yoon JW, Kim M, Jeong J, Ryu M, Park S, Jo C, Lee CK. 2020. Optimization of culture conditions for maintaining pig muscle stem cells in vitro. Food Sci Anim Resour 40:659.

Choudhury D, Tseng TW, Swartz E. 2020. The business of cultured meat. Trends Biotechnol 38:573-577.

Chriki S, Hocquette JF. 2020. The myth of cultured meat: a review. Front Nutr 7:7.

Clark DL, Coy CS, Strasburg GM, Reed KM, Velleman SG. 2016. Temperature effect on proliferation and differentiation of satellite cells from turkeys with different growth rates. Poult Sci 95:934-947.

Coles CA, Wadeson J, Leyton CP, Siddell JP, Greenwood PL, White JD, McDonagh MB. 2015. Proliferation rates of bovine primary muscle cells relate to liveweight and carcase weight in cattle. PLoS One 10:e0124468.

Djisalov M, Knežić T, Podunavac I, Živojević K, Radonic V, Knežević NŽ, Bobrinetskiy I, Gadjanski I. 2021. Cultivating multidisciplinarity: manufacturing and sensing challenges in cultured meat production. Biology 10:204.

Dridi L, Altamura F, Gonzalez E, Lui O, Kubinski R, Pidgeon R, Montagut A, Chong J, Xia J, Maurice C F, Castagner B. 2023. Identifying glycan consumers in human gut microbiota samples using metabolic labeling coupled with fluorescence-activated cell sorting. Nat Commun 14:662.

Fish KD, Rubio NR, Stout AJ, Yuen JS, Kaplan DL. 2020. Prospects and challenges for cell-cultured fat as a novel food ingredient. Trends Food Sci Technol 98:53-67.

Fraeye I, Kratka M, Vandenburgh H, Thorrez L. 2020. Sensorial and nutritional aspects of cultured meat in comparison to traditional meat: much to be inferred. Front Nutr 7:35.

Fülber J, Agreste FR, Seidel SR, Sotelo ED, Barbosa Â P, Michelacci YM, Baccarin RY. 2021. Chondrogenic potential of mesenchymal stem cells from horses using a magnetic 3D cell culture system. World J Stem Cells 13:645.

Furuhashi M, Morimoto Y, Shima A, Nakamura F, Ishikawa H, Takeuchi S. 2021. Formation of contractile 3D bovine muscle tissue for construction of millimetre-thick cultured steak. Sci Food 5:6.

Garrison GL, Biermacher JT, Brorsen BW. 2022. How much will large-scale production of cell-cultured meat cost?. J Agric Food Res 10:100358.

Goodwin JN, Shoulders CW. 2013. The future of meat: a qualitative analysis of cultured meat media coverage. Meat Sci 95:445-450.

Guan X, Lei Q, Yan Q, Li X, Zhou J, Du G, Chen J. 2021. Trends and ideas in technology, regulation and public acceptance of cultured meat. Future Foods 3:100032.

Guan X, Zhou J, Du G, Chen J. 2022. Bioprocessing technology of muscle stem cells: implications for cultured meat. Trends Biotechnol 40:721-734.

Guan X, Yan Q, Ma Z, Zhou J. 2023. Production of mature myotubes in vitro improves the texture and protein quality of cultured pork. Food Funct 14:3576-3587.

Hadi J, Brightwell G. 2021. Safety of alternative proteins: Technological, environmental and regulatory aspects of cultured meat, plant-based meat, insect protein and single-cell protein. Foods 10:1226.

Hong TK, Shin DM, Choi J, Do JT, Han SG. 2021. Current issues and technical advances in cultured meat production: a review. Food Sci Anim Resour 41:355.

Jairath G, Mal G, Gopinath D, Singh B. 2021. A holistic approach to access the viability of cultured meat: A review. Trends Food Sci Technol 110:700-710.

Jang M, Scheffold J, Bruheim P. 2022. Isolation and cultivation of primary muscle cells from Lobster (Homarus gammarus). In Vitro Cell Dev Biol Anim 58:446-451.

Jones JD, Rebello AS, Gaudette GR. 2021. Decellularized spinach: An edible scaffold for laboratory-grown meat. Food Biosci 41:100986.

Joo ST, Choi JS, Hur SJ, Kim GD, Kim CJ, Lee EY, Bakhsh A, Hwang YH. 2022. A comparative study on the taste characteristics of satellite cell cultured meat derived from chicken and cattle muscles. Food Sci Anim Resour 42:175.

Kadim IT, Mahgoub O, Baqir S, Faye B, Purchas R. 2015. Cultured meat from muscle stem cells: a review of challenges and prospects. J Integr Agric 14:222-233.

Ketelings L, Kremers S, de Boer A. 2021. The barriers and drivers of a safe market introduction of cultured meat: a qualitative study. Food Control 130:108299.

Kim SH, Kim CJ, Lee EY, Son YM, Hwang YH, Joo ST. 2022A. Optimal pre-plating method of chicken satellite cells for cultured meat production. Food Sci Anim Resour 42:942-952.

Kim B, Ko D, Choi SH, Park S. 2023B. Bovine muscle satellite cells in calves and cattle: a comparative study of cellular and genetic characteristics for cultivated meat production. Curr Res Food Sci 7:100545.

Kim CJ, Kim SH, Lee EY, Son YM, Bakhsh A, Hwang YH, Joo ST. 2023C. Optimal temperature for culturing chicken satellite cells to enhance production yield and umami intensity of cultured meat. Food Chem Adv 2:100307.

Kim S, Beier A, Schreyer HB, Bakshi BR. 2022B. Environmental life cycle assessment of a novel cultivated meat burger patty in the united states. Sustainability 14:16133.

Kim Y, Oh S, Park G, Park S, Park Y, Choi H, Kim M, Choi J. 2023A. Characteristics of bovine muscle satellite cell from different breeds for efficient production of cultured meat. J Anim Sci Technol.

Koranne V, Jonas OLC, Mitra H, Bapat S, Ardekani AM, Sealy MP, Rajukar K, Malshe AP. 2022. Exploring properties of edible hydrolyzed collagen for 3D food printing of scaffold for biomanufacturing cultivated meat. Procedia CIRP 110:186-191.

Langelaan ML, Boonen KJ, Polak RB, Baaijens FP, Post MJ, van der Schaft DW. 2010. Meet the new meat: tissue engineered skeletal muscle. Trends Food Sci Technol 21:59-66.

Lee DY, Lee SY, Jung JW, Kim JH, Oh DH, Kim HW, Kang JH, Choi JS, Kim GD, Joo ST, Hur SJ. 2022A. Review of technology and materials for the development of cultured meat. Crit Rev Food Sci Nutr. 1-25.

Lee DY, Lee SY, Yun SH, Jeong JW, Kim HW, Choi JS, Kim GD, Joo ST, Choi I, Hur SJ. 2022C. Review of the current research on fetal bovine serum and the development of cultured meat. Food Sci Anim Resour 42:775.

Lee SY, Lee DY, Jeong JW, Kim JH, Yun SH, Joo ST, Choi I, Choi JS, Kim GD, Hur SJ. 2023. Studies on meat alternatives with a focus on structuring technologies. Food Bioprocess Technol 16:1389-1412.

Lee SY, Yun SH, Jeong JW, Kim JH, Kim HW, Choi JS, Kim GD, Joo ST, Choi I, Hur SJ. 2022B. Review of the current research on fetal bovine serum and the development of cultured meat. Food Sci Anim Resour 42:775.

Levi S, Yen FC, Baruch L, Machluf M. 2022. Scaffolding technologies for the engineering of cultured meat: towards a safe, sustainable, and scalable production. Trends Food Sci Technol 126:13-25.

Li L, Chen L, Chen X, Chen Y, Ding S, Fan X, Liu Y, Xu X, Zhou G, Zhu B, Ullah N, Feng X. 2022B. Chitosan-sodium alginate-collagen/gelatin three-dimensional edible scaffolds for building a structured model for cell cultured meat. Int J Biol Macromol 209:668-679.

Li M, Wang D, Fang J, Lei Q, Yan Q, Zhou J, Chen J, Guan X. 2022A. An efficient and economical way to obtain porcine muscle stem cells for cultured meat production. Food Res Int 162:112206.

Li Y, Liu W, Li S, Zhang M, Yang F, Wang S. 2021. Porcine skeletal muscle tissue fabrication for cultured meat production using three-dimensional bioprinting technology. J Future Foods 1:88-97.

Louis F, Furuhashi M, Yoshinuma H, Takeuchi S, Matsusaki M. 2023. Mimicking wagyu beef fat in cultured meat: progress in edible bovine adipose tissue production with controllable fatty acid composition. Mater Today Bio 21:100720.

Luo W, Geng Y, Gao M, Cao M, Wang J, Yang J, Sun C, Yan X. 2022. Isolation and identification of bone marrow mesenchymal stem cells from forest musk deer. Animals 13:17.

Martins B, Bister A, Dohmen RG, Gouveia MA, Hueber R, Melzener L, Messmer T, Papadopoulos J, Pimenta J, Raina D, Schaeken L, Shirley S, Bouchet BP, Flack JE. 2023. Advances and challenges in cell biology for cultured meat. Annu Rev Anim Biosci 12.

McNaughton BH, Anker JN, Kinnunen PK. 2022. Buoyant-Antigen-Magnetic (BAM) immunoseparation, isolation, and detection of specific pathogenic bacterial cells. BioRxiv 2022-11.

Messmer T, Dohmen RG, Schaeken L, Melzener L, Hueber R, Godec M, Didoss C, Post MJ, Flack JE. 2023. Single-cell analysis of bovine muscle-derived cell types for cultured meat production. Front Nutr 10.

Ng S, Kurisawa M. 2021. Integrating biomaterials and food biopolymers for cultured meat production. Acta Biomater 124:108-129.

Nobre FS. 2022. Cultured meat and the sustainable development goals. Trends Food Sci Technol. 124:140-153.

Norris SC, Kawecki NS, Davis AR, Chen KK, Rowat AC. 2022. Emulsion-templated microparticles with tunable stiffness and topology: applications as edible microcarriers for cultured meat. Biomater 287:121669.

Oh S, Park S, Park Y, Kim YA, Park G, Cui X, Kim K, Joo S, Hur S, Kim G, Choi J. 2023. Culturing characteristics of Hanwoo myosatellite cells and C2C12 cells incubated at 37° C and 39° C for cultured meat. J Anim Sci Technol 65:664.

Okamoto Y, Haraguchi Y, Yoshida A, Takahashi H, Yamanaka K, Sawamura N, Asahi T, Shimizu T. 2022. Proliferation and differentiation of primary bovine myoblasts using Chlorella vulgaris extract for sustainable production of cultured meat. Biotechnol Progr 38:e3239.

Ong KJ, Tejeda-Saldana Y, Duffy B, Holmes D, Kukk K, Shatkin JA. 2023. Cultured meat safety research priorities: regulatory and governmental perspectives. Foods 12:2645.

Onwezen MC, Bouwman EP, Reinders MJ, Dagevos H. 2021. A systematic review on consumer acceptance of alternative proteins: pulses, algae, insects, plant-based meat alternatives, and cultured meat. Appetite 159:105058.

Pakseresht A, Kaliji SA, Canavari M. 2022. Review of factors affecting consumer acceptance of cultured meat. Appetite 170:105829.

Paredes J, Cortizo-Lacalle D, Imaz AM, Aldazabal J, Vila M. 2022. Application of texture analysis methods for the characterization of cultured meat. Sci Rep 12:3898.

Park J, Lee J, Song KD, Kim SJ, Kim DC, Lee SC, Son YJ, Choi HW, Shim K. 2021. Growth factors improve the proliferation of Jeju black pig muscle cells by regulating myogenic differentiation 1 and growth-related genes. Anim Biosci 34:1392.

Pasitka L, Cohen M, Ehrlich A, Gildor B, Reuveni E, Ayyash M, Wissotsky G, Herscovici A, Kaminker R, Niv A, Bitcover R, Dadia O, Rudik A, Voloschin A, Shimoni M, Cinnamon Y, Nahmias Y. 2023. Spontaneous immortalization of chicken fibroblasts generates stable, high-yield cell lines for serum-free production of cultured meat. Nat Food 4:35-50.

Perruchot MH, Ecolan P, Sorensen IL, Oksbjerg N, Lefaucheur L. 2012. In vitro characterization of proliferation and differentiation of pig satellite cells. Differ 84:322-329.

Piochi M, Micheloni M, Torri L. 2022. Effect of informative claims on the attitude of Italian consumers towards cultured meat and relationship among variables used in an explicit approach. Food Res Int 151:110881.

Post MJ, Levenberg S, Kaplan DL, Genovese N, Fu J, Bryant CJ, Negowetti N, Verzijden K, Moutsatsou P. 2020. Scientific, sustainability and regulatory challenges of cultured meat. Nat Food. 1:403–415.

Post MJ. 2012. Cultured meat from stem cells: challenges and prospects. Meat Sci 92:297-301.

Promtan P, Panatuk J, Kongbuntad W, Amornlerdpison D, Nanta Y, Pripwai N, Thaworn W, Pattanawong W. 2023. Growth and development of black-boned chicken embryonic stem cells for culture meat using different serums as medium. Fac Anim Sci 46:354-360

Ramani S, Ko D, Kim B, Cho C, Kim W, Jo C, Lee CK, Kang J, Hur S, Park S. 2021. Technical requirements for cultured meat production: a review. J Anim Sci Technol 63:681.

Rao KM, Choi SM, Han SS. 2023. A review on directional muscle cell growth in scaffolding biomaterials with aligned porous structures for cultivated meat production. Food Res Int 112755.

Rolland NC, Markus CR, Post MJ. 2020. The effect of information content on acceptance of cultured meat in a tasting context. PLoS One 15:e0231176.

Rombach M, Dean D, Vriesekoop F, de Koning W, Aguiar LK, Anderson M, Mongondry P, Oppong-Gyamfi M, Urbano B, Luciano CAG, Hao W, Eastwick E, Jiang Z, Boereboom A. 2022. Is cultured meat a promising consumer alternative? Exploring key factors determining consumer's willingness to try, buy and pay a premium for cultured meat. Appetite 179:106307.

Rubio NR, Xiang N, Kaplan DL. 2020. Plant-based and cell-based approaches to meat production. Nat Commun 11:6276.

Saadeldin IM, Swelum AAA, Noreldin AE, Tukur HA, Abdelazim AM, Abomughaid MM, Alowaimer AN. 2019. Isolation and culture of skin-derived differentiated and stem-like cells obtained from the Arabian camel (Camelus dromedarius). Animals 9:378.

Seah JSH, Singh S, Tan LP, Choudhury D. 2022. Scaffolds for the manufacture of cultured meat. Crit Rev Biotechnol 42:311-323.

Siddiqui SA, Bahmid NA, Karim I, Mehany T, Gvozdenko AA, Blinov AV, Nagdalian AA, Arsyad M, Lorenzo JM. 2022A. Cultured meat: processing, packaging, shelf life, and consumer acceptance. LWT 172:114192.

Siddiqui SA, Khan S, Murid M, Asif Z, Oboturova NP, Nagdalian AA, Blinov AV, Ibrahim SA, Jafari SM. 2022B. Marketing strategies for cultured meat: a review. Appl Sci 12:8795.

Singh S, Yap WS, Ge XY, Min VLX, Choudhury D. 2022. Cultured meat production fuelled by fermentation. Trends Food Sci Technol 120:48-58.

Singh S, Yap WS, Ge XY, Min VLX, Choudhury D. 2022. Cultured meat production fuelled by fermentation. Trends Food Sci Technol 120:48-58.

Skrivergaard S, Rasmussen MK, Sahebekhtiari N, Young JF, Therkildsen M. 2023. Satellite cells sourced from bull calves and dairy cows differs in proliferative and myogenic capacity–Implications for cultivated meat. Food Res Int 173:113217.

Song WJ, Liu PP, Meng ZQ, Zheng YY, Zhou GH, Li HX, Ding SJ. 2022. Identification of porcine adipose progenitor cells by fluorescence-activated cell sorting for the preparation of cultured fat by 3D bioprinting. Food Res Int 162:111952.

Starowicz M, Poznar KK, Zieliński H. 2022. What are the main sensory attributes that determine the acceptance of meat alternatives?. Curr Opin Food Sci 100924.

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 Food Sci Technol 78:155-166.

Stout AJ, Mirliani AB, Soule-Albridge EL, Cohen JM, Kaplan DL. 2020. Engineering carotenoid production in mammalian cells for nutritionally enhanced cell-cultured foods. Metab Eng 62:126-137.

Stout AJ, Mirliani AB, Rittenberg ML, Shub M, White EC, Yuen Jr, Kaplan DL. 2022. Simple and effective serum-free medium for sustained expansion of bovine satellite cells for cell cultured meat. Commun Biol 5:466.

Sui M, Zheng Q, Wu H, Ding J, Liu Y, Li W, Chu M, Zhang Z, Ling Y. 2018. Isolation, culture and myogenic differentiation of muscle stem cells in goat fetal. Sci Agric Sin 51:1590-1597.

Swatler J, Dudka W, Piwocka K. 2020. Isolation and characterization of extracellular vesicles from cell culture conditioned medium for immunological studies. Curr Protocol Immunol 129:e96.

Tomiyama AJ, Kawecki NS, Rosenfeld DL, Jay JA, Rajagopal D, Rowat AC. 2020. Bridging the gap between the science of cultured meat and public perceptions. Trends Food Sci Technol 104:144-152.

Treich N. 2021. Cultured meat: promises and challenges. Environ Resour Econo 79:33-61.

van der Valk J. 2022. Fetal bovine serum—a cell culture dilemma. Sci 375:143-144.

Vegusdal A, Sundvold H, Gjøen T, Ruyter B. 2003. An in vitro method for studying the proliferation and differentiation of Atlantic salmon preadipocytes. Lipids 38:289-296.

Verbeke W, Sans P, Van Loo EJ. 2015. Challenges and prospects for consumer acceptance of cultured meat. J Integr Agric 14:285-294.

Wang S, Zhang Y, Xu Q, Yuan X, Dai W, Shen X, Wang Z, Chang G, Wang Z, Chen G. 2018. The differentiation of preadipocytes and gene expression related to adipogenesis in ducks (Anas platyrhynchos). PLoS One 13:e0196371.

Wollschlaeger JO, Maatz R, Albrecht FB, Klatt A, Heine S, Blaeser A, Kluger PJ. 2022. Scaffolds for cultured meat on the basis of polysaccharide hydrogels enriched with plant-based proteins. Gels 8:94.

Yuliarti O, Kovis TJK, Yi NJ. 2021. Structuring the meat analogue by using plant-based derived composites. J Food Eng 288:110138.

Zernov A, Baruch L, Machluf M. 2022. Chitosan-collagen hydrogel microparticles as edible cell microcarriers for cultured meat. Food Hydrocolloids 129:107632.

Zhang G, Zhao X, Li X, Du G, Zhou J, Chen J. 2020. Challenges and possibilities for bio-manufacturing cultured meat. Trends Food Sci Technol 97:443-450.

Zhang S, Lou H, Lu H, Xu E, Liu D, Chen Q. 2023. Characterization of proliferation medium and Its effect on differentiation of muscle satellite cells from larimichthys crocea in cultured fish meat production. Fishes 8:429.

Zhao Y, Guo L, Guo H. 2023. Routine development of long-term primary cell culture and finite cell line from the hemolymph of greasyback shrimp (Metapenaeus ensis) and virus susceptibility. Aquacult 563:739007.

Zheng YY, Zhu HZ, Wu ZY, Song WJ, Tang CB, Li CB, Ding SJ, Zhou GH. 2021. Evaluation of the effect of smooth muscle cells on the quality of cultured meat in a model for cultured meat. Food Res Int 150:110786.

Zhu H, Wu Z, Ding X, Post MJ, Guo R, Wang J, Wu J, Tang W, Zhou G. 2022. Production of cultured meat from pig muscle stem cells. Biomater 287:121650.

Zhu G, Gao D, Li L, Yao Y, Wang Y, Zhi M, Zhang J, Chen X, Zhu Q, Gao J, Chen T, Zhang X, Wang T, Cao S, Ma A, Feng X, Han J. 2023. Generation of three-dimensional meat-like tissue from stable pig epiblast stem cells. Nat Commun 14:8163.

Tables and Figures

Table 1. Types of cell donors for manufacturing cultured meat

Cell source	Breed	Cell kind	Product form	Reference
Bovine	Simmental	Primary bovine satellite cells	Muscle tissue form	Stout et al. (2022)
	Japanese black	Bovine myocytes	Steak form	Furuhashi et al. (2021)
	Belgian Blue	Mixed cells	Muscle tissue form	Messmer et al. (2023)
	Jeju black	Satellite cells	Muscle tissue form	Kim et al. (2023)
	Holstein Friesian	Peri-renal adipose cells	Fat tissue form	Okamoto et al. (2022)
Swine	LYD (Landrace×Yorkshire ×Duroc)	Muscle stem cells	Muscle tissue form	Choi et al. (2020)
	Nongda Xiang	Muscle stem cells	Muscle tissue form	Zhu et al. (2023)
	Jeju black	Muscle stem cells	Muscle tissue form	Park et al. (2021)
	Pietrain X (Large White×Landrace)	Satellite cells	Muscle tissue form	Perruchot et al. (2012)
	Large white	Satellite cells	Steak form	Guan et al. (2023)
Poultry	Hy-line brown (Chicken)	Satellite cells	Muscle tissue form	Kim et al. (2023C)
	Broiler Ross (Chicken)	Primary fibroblast cells	Steak form	Pasitka et al. (2023)
	Black-bone (Chicken)	Embryonic stem cells	Muscle tissue form	Promtan et al. (2023)
	Cherry Valley White-crested Jianchang (Duck)	Pre-adipocytes cells	Fat tissue form	Wang et al. (2018)
	Turkey	Satellite cells	Muscle tissue form	Clark et al. (2016)
Mammalian	Sheep	Satellite cells	Muscle tissue form	Carpenter et al.

				(2000)
	Goat	Muscle stem cells	Muscle tissue form	Sui et al. (2018)
	Horse	Mesenchymal stem cells	Chondrogenic tissue form	Fülber et al. (2021)
	Camel	Skin fibroblasts cells	Skin tissue form	Saadeldin et al. (2019)
	Deer	Mesenchymal stem cells	Muscle tissue form	Luo et al. (2022)
Fishery	Atlantic salmon	Adipose cells	Fat tissue form	Vegusdal et al. (2003)
	Large yellow croaker	Piscine satellite cells	Muscle tissue form	Zhang et al. (2023)
	Bluefin tuna	Cells	Tissue form	Bain et al. (2013)
	Greasyback shrimp	Cells	Tissue form	Zhao et al. (2023)
	Lobster	Primary muscle cells	Muscle tissue form	Jang et al. (2022)

Table 2. Differences of cell isolation methods

Characteristics	FACS	MACS	Hybrid
Surface antigens	Not essential	Essential	Not essential
Fluorescence cell labeling	Required	Not Required	Required
Cell purity	High	Medium	High
Concurrent categorization of diverse groups	Possible	Not possible	Possible
Categorizing by varied levels of expression	Possible	Not Possible	Possible
Cell separation	Trypsinize	Magnetic	Complex
Positive selection	Possible	Possible	Possible
Negative selection	Possible	Possible (low purity)	Possible
Multi marker selection	Possible	Very limited	Possible
Operation specificity	High	High	High
Equipment price	High	Low	High
Technical proficiency	Highly required	Low required	Highly required

Table 3. Types of cell donors for manufacturing cultured meat

Cell source	Breed	Cell kind	Product form	Reference
Bovine	Simmental	Primary bovine satellite cells	Muscle tissue form	Stout et al. (2022)
	Japanese black	Bovine myocytes	Steak form	Furuhashi et al. (2021)
	Belgian Blue	Mixed cells	Muscle tissue form	Messmer et al. (2023)
	Jeju black	Satellite cells	Muscle tissue form	Kim et al. (2023)
	Holstein Friesian	Peri-renal adipose cells	Fat tissue form	Okamoto et al. (2022)
Swine	LYD (Landrace×Yorkshire ×Duroc)	Muscle stem cells	Muscle tissue form	Choi et al. (2020)
	Nongda Xiang	Muscle stem cells	Muscle tissue form	Zhu et al. (2023)
	Jeju black	Muscle stem cells	Muscle tissue form	Park et al. (2021)
	Pietrain X (Large White×Landrace)	Satellite cells	Muscle tissue form	Perruchot et al. (2012)
	Large white	Satellite cells	Steak form	Guan et al. (2023)
Poultry	Hy-line brown (Chicken)	Satellite cells	Muscle tissue form	Kim et al. (2023C)
	Broiler Ross (Chicken)	Primary fibroblast cells	Steak form	Pasitka et al. (2023)
	Black-bone (Chicken)	Embryonic stem cells	Muscle tissue form	Promtan et al. (2023)
	Cherry Valley White-crested Jianchang (Duck)	Pre-adipocytes cells	Fat tissue form	Wang et al. (2018)
	Turkey	Satellite cells	Muscle tissue form	Clark et al. (2016)
Mammalian	Sheep	Satellite cells	Muscle tissue form	Carpenter et al. (2000)
	Goat	Muscle stem cells	Muscle tissue form	Sui et al. (2018)
	Horse	Mesenchymal stem	Chondrogenic tissue	Fülber et al.

		cells	form	(2021)
	Camel	Skin fibroblasts cells	Skin tissue form	Saadeldin et al. (2019)
	Deer	Mesenchymal stem cells	Muscle tissue form	Luo et al. (2022)
Fishery	Atlantic salmon	Adipose cells	Fat tissue form	Vegusdal et al. (2003)
	Large yellow croaker	Piscine satellite cells	Muscle tissue form	Zhang et al. (2023)
	Bluefin tuna	Cells	Tissue form	Bain et al. (2013)
	Greasyback shrimp	Cells	Tissue form	Zhao et al. (2023)
	Lobster	Primary muscle cells	Muscle tissue form	Jang et al. (2022)

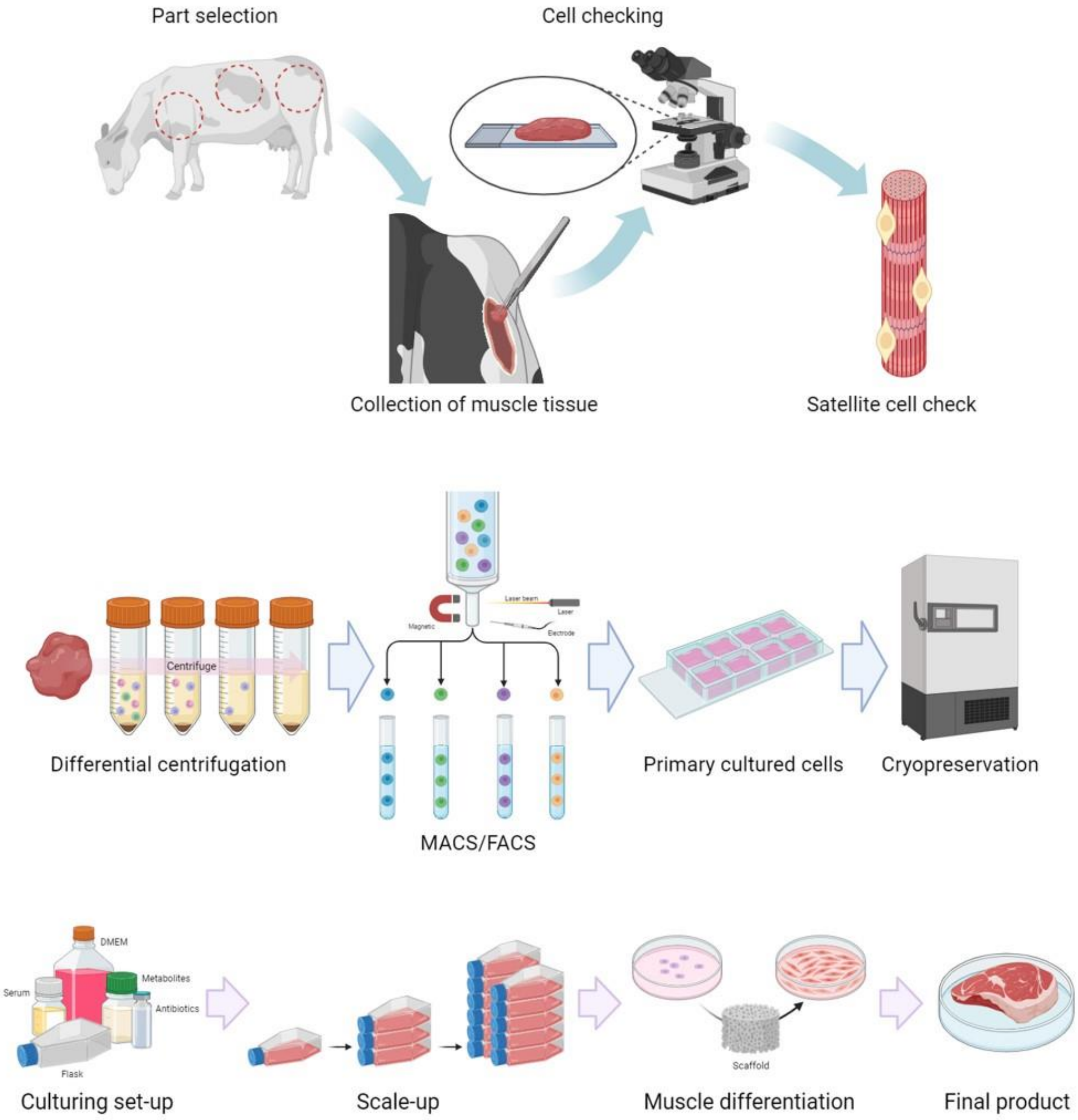

Figure 1. The whole process for manufacturing cultured meat.