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Development of Cultured Meat Technology in China

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Abstract: Cultured meat is a new meat product that is produced by an ex vivo culture of animal cells instead of livestock farming. In addition, this method is considered a promising solution to problems caused by traditional livestock production, such as resource consumption, environmental pollution, and public health issues. This study analyzed cultured meat, focusing on its production processes, key technologies, international development trends, and challenges in China's cultured meat industry, to develop recommendations for cultured meat technology development in China. Cultured meat production requires the integration of advanced technologies from multi-disciplinary fields including cell biology, tissue engineering, fermentation engineering, and food engineering. The global development of cultured meat technology is in its infancy and progressive stages. Although industry-leading companies have achieved technological integration and industrialization demonstrations, the industrial production of cultured meat has not yet been realized, and various key technological barriers need to be resolved. It was found that in China, the cultured meat industry started late, and its technological development faces problems such as weak research foundations, single research ideas, and slow industrialization processes. In the future, China should increase policy and financial support for research in this area and strengthen interdisciplinary exchanges and academic-enterprise cooperation. Furthermore, more attention must be given to consumer appetite and nutritional needs.

Keywords: cultured meat; muscle tissue; stem cell expansion; induced differentiation; food process

1 Introduction

According to the Food and Agriculture Organization (FAO) of the United Nations and the United Nations Population Division, the global population will increase to 9 billion by 2050, while the average annual meat consumption demand will rise to 4.65×10^8 t (twice as much as the total production in 2000) [1]. In China, the supply and demand of meat products have shown a significant imbalance in recent years. For example, in 2020, the meat import volume was 9.91×10^6 t, which was approximately 60% year-on-year. Moreover, meat consumption per capita is expected to increase twofold in 2030 compared to 2010 [2]. Securing meat supply for human consumption with limited resources will become a major challenge. Meat production methods that rely on traditional agriculture are increasingly in conflict with natural resources and environmental protection. Livestock breeding consumes a significant amount of water, land, and other resources and emits a large concentration of greenhouse gases that enhance the greenhouse effect. Additionally, it is associated with unfavorable animal ethics and public health problems [3]. The FAO reports [4] that the production of 1 kg of beef consumes approximately 40 m^2 of land, 15 m^3 of water, and produces 300 kg of CO_2 equivalent; one-third of the available land in the world is used for agriculture, most of which is used for livestock pasture. Of the total crop production, 30% is used for

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animal feed crops, but unfortunately, the material conversion efficiency of the whole ecological chain is extremely low because of the low conversion rate of feed material [4]. The prevalence of widespread animal diseases, such as African swine fever, avian influenza, and mad cow disease, has brought significant challenges to the traditional breeding industry, which requires substantial material and financial resources to ensure the safety of meat, thus causing a significant increase in the cost of meat production [5]. In addition, with the development of the economy and society, the dietary needs of consumers have shifted from satiety to health, hygiene, taste, and nutrition. Therefore, there is an urgent need to develop more efficient, environmentally friendly, and sustainable meat production systems to meet consumer demand for higher quantity and quality of meat.

Cultivated meat, also known as cultured meat, is an important discipline of cellular agriculture. Based on the mechanism of muscle tissue development and damage repair, muscle tissues can be constituted in vitro by culturing animal cells to produce muscle fibers, fat, and other cell types using cell biology and tissue engineering techniques; after collection, shaping, and food processing, edible meat products can be manufactured [6]. These production technologies have the advantages of extremely high resource conversion, environmental sustainability, and animal friendliness. Compared to traditional meat production, cultivated meat provides a source of real animal protein to the population without the need for feeding and slaughtering livestock. Furthermore, the production cycle is only one-tenth of traditional meat, which can quickly fill the meat market gap and stabilize the price of meat products [7]; in addition, it can effectively alleviate or solve the social and environmental problems associated with traditional agriculture, such as hormone and antibiotic abuse, environmental pollution, and animal ethics [8]. Therefore, cultivated meat is regarded as one of the most potentially disruptive solutions to the imbalance between the production and consumption of meat products in the future. The development of cultivated meat production technology is of positive significance for ensuring an adequate supply of meat products, promoting the optimal allocation of resources, facilitating the transformation and upgrading of traditional agricultural models, and maintaining sustainable economic and social development.

Focusing on the development of production technology and market demand of cultivated meat in China, this paper discusses the production process and main steps in cultivated meat. Furthermore, the authors analyzed the key technological barriers and basic scientific challenges in the industrialized production of cultivated meat, investigated the development situation of the global cultivated meat industry, and analyzed the developing process and problems in cultivated meat technology of China. Finally, directions for technological development and industry development strategies are proposed to provide a basic reference for the technological and industrial development of cultivated meat in China.

2 Key technologies for the production of cultivated meat

The concept of cultivated meat has been validated with the rapid development of disciplines such as cell biology and tissue engineering. Its production involves the acquisition of seed cells, in vitro expansion of seed cells, myogenic or adipogenic differentiation, and food processing (Fig. 1). However, the industrial production of cultivated meat has not yet been fully realized and is limited by several key technologies.

2.1 Efficient seed cell acquisition technology

Muscle stem cells, embryonic stem cells, induced pluripotent stem cells, and mesenchymal stem cells, which have the potential to differentiate into muscle cells or adipocytes, can be used as seed cells in meat cultivation. Several types of stem cells differ in their developmental stage, location in the body, and pluripotency, resulting in the need for different methods and complexities to obtain them. Therefore, specific isolation and purification protocols need to be developed for various cell types to realize the efficient acquisition of seed cells, which provides the basic conditions for the subsequent steps in cultivated meat production.

Embryonic stem cells are totipotent, which, theoretically, can proliferate infinitely and have the potential for multidirectional differentiation [9]. However, the establishment of stable embryonic stem cell lines is extremely difficult, especially for pigs, cattle, and wild fish.

Induced pluripotent stem cells are obtained from adult cells such as fibroblasts, using genetic reprogramming techniques [10]. Porcine-induced pluripotent stem cells have been successfully prepared and may become a seed cell type for cultivated meat production [11]. Notably, the in vitro culture conditions of induced pluripotent stem cells are extremely complex and relatively difficult to manipulate, and the efficiency of proliferation and myogenic differentiation needs to be further improved to meet the requirements for the industrial production of cultured meat.

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Mesenchymal stem cells and muscle stem cells are both adult stem cells with a self-renewal ability and potential for multi-directional or directional differentiation. Mesenchymal stem cells are usually isolated from bone marrow and adipose tissues, which are widely available, simple to obtain, and easy to purify and expand in culture. In vitro, they can be differentiated into adipocytes, osteoblasts, and myoblasts based on different induction conditions [12]. The lipogenic differentiation capacity is relatively high; therefore, they can be used as seed cells to produce adipose tissues. Muscle stem cells are specialized stem cells in muscle tissues and have a strong capacity for myogenic differentiation, which can be isolated from fresh muscle tissues. After reaching sufficient numbers through proliferation, cells can differentiate, fuse, and form myotubes; therefore, they are commonly used as preferred seed cells for muscle fiber production [13].

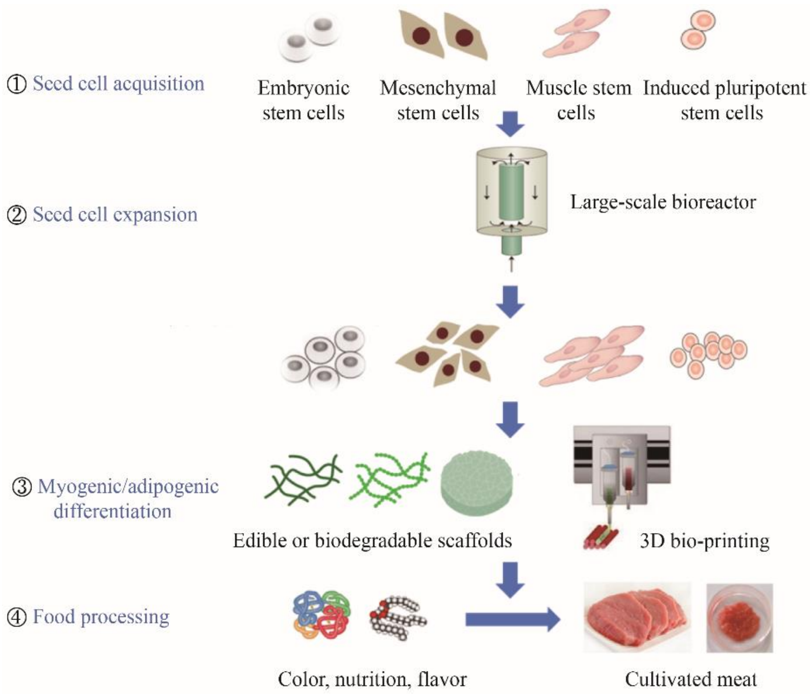

Fig. 1. Production process of cultivated meat.

2.2 Cell cryopreservation technology

Seed cells that are freshly isolated from tissues or after expansion may need to be reliably stored for an extended period before they are induced to differentiate into muscle fibers for manufacturing cultivated meat products. Cryopreservation of stem cells has higher technical and condition requirements than that of conventional cells. Factors such as osmotic pressure, free radicals, protective agents, and low temperature during the freezing/resuscitation process, may induce non-directional differentiation of stem cells. In addition to improving cell survival rate, the effect of the freezing process on cell differentiation must also be considered to obtain the expected freezing efficiency.

Cryoprotectants are added before cell freezing to protect cells from freezing damage and thus improve cell survival after recovery; cryoprotectants are divided into two categories: permeable and non-permeable [14]. Permeable cryoprotectants are mainly small-molecule chemicals such as dimethyl sulfoxide (DMSO) and glycerol while non-permeable cryoprotectants are mostly large-molecule substances (e.g., sugars). Recent studies have used DMSO as a cryoprotectant for cells, attributing its use to high cell survival and adhesion rates after cell recovery [15]. The cryopreservation process of stem cells should use a program-controlled cooling instrument, and strictly control the cooling rate (1 to 3 ℃/min); the cooling rate could be accelerated after the phase change heat release stage (−15 to −11℃), and cells could be transferred to liquid nitrogen (−196 ℃) for long-term storage after the temperature is lowered between −80℃ and −90 ℃.

Food safety of cell cryoprotectants needs to be investigated prior to the large-scale production of cultured meat. Whether cells treated with DMSO or other cryoprotectants can be used as food-safe cells for the production of cultured meat needs to be evaluated in-depth. Furthermore, the study results can inform the direction of regulatory policies and legislation formulation.

2.3 In vitro expansion technology

To maintain the normal growth and function of stem cells in vitro, it is necessary to not only place the cells in a sterile environment with an appropriate temperature, pH, and humidity, but also provide the cells with the basic nutrients required for growth (i.e., culture medium). The expansion medium for stem cells commonly consists of a basal medium, serum, cytokines, and other additives. Different species and types of stem cells have different preferences for culture media, and the optimal basal medium requires case-by-case screening. Given the high purchasing cost of a basal medium, the composition of its constituents should be optimized with equivalent low-cost substitutions, which will reduce the costs in industrial-scale meat cultivation.

The serum is also a key factor affecting the growth behavior of stem cells in vitro, and many stem cells need to be cultured in media containing fetal bovine serum (FBS) (usually 10%–20%). However, it is difficult to realize the quality control of FBS owing to its high price, complex and unclear nutritional composition, and significant batch-to-batch variation [16]. Therefore, the establishment of a serum-free medium with a well-defined chemical composition is essential for the commercial production of cultured meat as it can reduce production costs and ensure the controllability and accuracy of the production process. In addition, the screening of various types of nutrients such as cytokines, glycoproteins, and small-molecule compounds and adding them to the culture medium according to the cell proliferation regulatory mechanism are crucial for enhancing cell proliferation and developing serum-free medium [17].

The design and development of suitable intelligent bioreactors to optimize and control the scale-up process is a prerequisite for the industrial production of cultivated meat. Currently, bioreactors that can be used for cultivated meat production include the wave reactor, fixed-bed bioreactor, stirred tank bioreactor, air-lift bioreactor, and perfusion bioreactor, but the optimal bioreactors for industrial production still need to be explored. Furthermore, process analysis techniques to obtain optimal process parameters, media recycling techniques, and cell retention techniques are important prerequisites for ensuring product quality and reducing production costs during the industrial production of cultured meat [18].

2.4 Induced differentiation technology

Muscle fibers are the most important basic components of muscle tissues. Once the animal stem cells complete their extensive proliferation and reach a sufficient cell number, they are induced to differentiate into muscle fibers and produce a large number of proteins (e.g., myosin, actin, and myoglobin). Muscle stem cells can spontaneously differentiate into muscle fibers in vivo, whereas an in vitro differentiation medium containing 2% horse serum is necessary to induce differentiation [19]. The myogenic differentiation efficiency of muscle stem cells is greatly influenced by the composition of the culture medium and culture conditions, and the in vitro differentiation efficiency is usually less than 50%. For totipotent stem cells, a more precise regulatory strategy is required; otherwise, their myogenic differentiation efficiency will be insufficient.

Fat gives muscles their marbling pattern and enhances the flavor and texture of the meat; thus, another research focus in the cultivated meat field is the efficient production of fat cells. The application of dexamethasone, 3-isobutyl-1-methylxanthine, insulin, and indomethacin alone or in combination, induces the differentiation of mesenchymal stem cells into adipocytes [20]. Furthermore, whether adipose cells produced in vitro, which contain fatty acids, triglycerides, and other flavor substances, can meet the requirements of meat products needs to be studied extensively.

2.5 3D molding technology

The production of muscle tissues with texture, taste, and flavor resembling that of real animal meat is the aim of cultured meat, and improving the size and thickness of cultured meat products is the current research focus and challenge. The culture flasks or dishes normally used in the laboratory can only culture cells in two-dimensional monolayers, whereas the formation of three-dimensional muscle tissue requires the use of cell scaffolds. In the physiological state, the cellular matrix composed mainly of collagen, adhesins, and glycoproteins wraps the myofibers, providing them with nutrients and form. The basis of the cellular scaffold required for in vitro culture is to mimic the components of the extracellular matrix so that cells can adhere, obtain nutrients, and grow dependent

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on it. A research team [21] made spun silk from edible gelatin and implanted rabbit skeletal muscle myogenic cells into it to obtain a final molded product with a texture similar to the real meat, which provided a breakthrough for the direction of future research.

To minimize the use of animal-derived components involved in the production of cultivated meat, the screening of plant-derived proteins (e.g., soy protein), natural polysaccharide-based macromolecules (e.g., chitosan), and synthetic materials (e.g., polyglutamic acid and polylactic acid) as cell scaffolding materials for tissue shaping of cultured meat is a current research attraction. The rapid rise and flourishing of 3D printing technology have provided new facilities for the manufacture of cultured meat [22]. Various types of living cell 3D printing devices have been introduced, and studies have confirmed that cells have a survival rate of 90% after 3D printing and can adhere, migrate, and grow within the 3D space of the printed shape. The combination of 3D printing technology to achieve the hybrid printing of different cell types (e.g., muscle cells and fat cells) and cell co-culture technology, can achieve the synergistic growth of different cell types under uniform medium composition and culture conditions, which will be an important technical way to produce meat products with complex structure and large size cultivation.

2.6 Food processing technology

The process of producing cultured meat inevitably involves making cultured meat products more food-specific. The most basic requirement for cultured meat to occupy a place in the future market is to be comparable or better than traditional meat products in terms of nutrition, taste, visualization, and flavor. For example, the heme content in muscle cells cultured in vitro is quite low, so it is necessary to add heme-rich hemoglobin and food coloring to simulate the color of meat; the source of meat flavor is lipid oxidation and maillard reaction, and some small molecule compounds (e.g., amino acids) are the main cause of “meat flavor” [23]. Therefore, the addition of hemoglobin, flavor substances, and unsaturated fatty acids through food processing technology is an important strategy to strengthen the color, aroma, and flavor of cultivated meat products and to gain consumers’ favor.

3 Development trends of the global cultivated meat industry

3.1 Scientific research institutions lead the industry

Beginning in 2000, scientific communities in the United States and Europe began the technical and commercial evaluation of cultivated meat. In 2008, the first international symposium on in-vitro meat was held at the Norwegian Food Research Institute. In 2011, researchers at the University of Oxford published the first review investigating and assessing the lifecycle impact of cultivated meat [24]. In 2012, scholars at the Maastricht University in the Netherlands conducted a proof-of-concept and technical study on cultivated meat and created the world’s first cultivated beef burger [6]. Subsequently, research institutions in the United States, Japan, and South Korea initiated research and development of cultivated meat, which promoted the rapid development of cultivated meat production technology.

According to preliminary statistics, nearly 400 papers related to cultivated meat have been published, with the top 10 institutions in the Netherlands, United Kingdom, France, Switzerland, United States, and Singapore, among which the representative ones are the Wageningen University, University of Oxford, and French Institute of Agriculture, Food, and Environment. Of these papers, more than 80% are review articles, which summarize and analyze the environmental impact, scale cost, technical feasibility, consumer acceptance, and management regulations of cultivated meat; approximately 10% are research articles that discuss the progress of key technologies in cultivated meat production, such as the long-term stable expansion technology of animal stem cells, bioreactor design for large-scale cell expansion, and 3D printing technology for cultivated meat molding. Although developed countries have early involvement in the research and development of technology for cultured meat, the technology has not yet been optimized; therefore, there is great potential for technological development.

3.2 Rapid growth of start-ups

In recent years, there has been a rapid growth in the number of international start-ups in the cultivated meat sector, with more than 60 engaged in the cultivation of meat products, equipment, and raw materials for the production process [7]. These companies are located in 20 countries on five continents, with approximately 37% in North America, 25% in Asia, 31% in Europe, and 7% in other regions. Memphis Meats (US) is the industry leader and has completed a Series B round funding of 181 million USD. Several promising start-ups have also received capital market support, including Mosa Meat (Netherlands), BlueNalu (US), Future Meat (Israel), Shoik Meats (Singapore), and Cubiq Foods (Spain), each of which has raised over 20 million USD.

The costs of industrialized products incurred by cultivated meat companies are shown in Fig. 2. In 2013, Mosa Meat's biologically grown beef burger meat cost approximately 325 000 USD (85 g), whereas 7 years later, the cost of building biologically grown beef dropped to 11.20 USD per hundred grams. According to Future Meat, the cost of cell-grown chicken decreased from 44 USD per hundred grams in 2019 to 3.90 USD per hundred grams in 2021, making it the lowest production cost in the cultivated meat segment today. In late 2020, regulators in Singapore, approved Eat Just's application to allow the public sale of biologically grown chicken, signaling the launch of the world's first cultivated meat product. Overall, there is an abundance of cultivated meat product types available internationally, and the continuous technological research and development brought about a significant reduction in production costs. The cell culture system and medium formulation, which are related to the production cost, are the trade secrets of the companies concerned, and thus form a technical and market barrier.

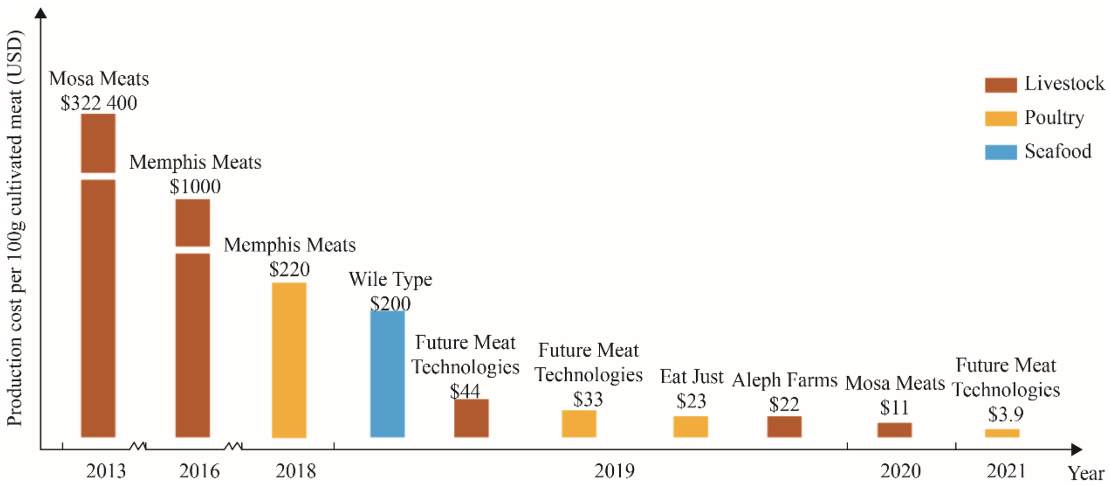

Fig. 2. Industrialization products and cost of cultivated meat enterprises.

4 Current status and challenges in the development of cultivated meat technology in China

4.1 Development status of cultivated meat technology

4.1.1 Research institutions and enterprises

In recent years, China has begun to pay attention to and actively promote the development of its cultivated meat industry. Several universities and research institutes have been involved in the research on cultivated meat technology, and the number of published papers and applied patents is growing rapidly. Universities, research institutes, and start-ups that are conducting research on cultivated meat in China are listed in Table 1.

Table 1. Research institutions and enterprises in the cultivated meat industry of China.

Name	Property	Region	Establishment/starting research time	Technology/product
Nanjing Agricultural University	University	Nanjing	2009	Regulation of cell proliferation and differentiation, scaffolding materials and manufacturing, and bioprocessing technology and equipment development, etc.
China Meat Food Research Center	Research institution	Beijing	2018	
Jiangnan University	University	Wuxi	2019	
Zhejiang University	University	Hangzhou	2020	
Avant Meats	Enterprise	Hong Kong	2018	Cultivated seafood
CellX	Enterprise	Shanghai	2020	Cultivated pork
Joes Future Food	Enterprise	Nanjing	2020	Cultivated pork

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The research team at Nanjing Agricultural University was the first to engage in cultivated meat technology in China. In 2019, they announced its first production of cultivated meat in China, which was obtained by culturing porcine muscle stem cells in vitro for 20 days and then differentiating them. Research teams at the China Meat Food Research Center, Jiangnan University, and Zhejiang University have also successively conducted research on technology development and elemental scientific challenges in cultivated meat production. These research areas include the regulation of animal stem cell proliferation and differentiation in vitro, scaffolding materials, and manufacturing processes, and bioprocessing technology and equipment development. Their studies covered various livestock and aquatic animal species such as pigs, cattle, chickens, pigeons, and fish. In terms of enterprises, there are three existing domestic cultivated meat enterprises, which are Avant Meats (Hong Kong), Joes Future Food (Nanjing), and CellX (Shagnhai). In addition, several consulting and investment institutions, such as GFI Consultancy Co., Bits×Bites Capital, and Lever Capital, are focusing on research and investigation, capital investment, and technical services for the entire alternative protein industry, including cultivated meat.

4.1.2 Cultivated meat-related patents and products

Since 2018, domestic cultivated meat start-ups are being gradually established and gaining active support from the capital market. There were 21 applications for patents in domestic cultivated meat from 2018 to 2020, with the number of applications increasing annually (Fig. 3); the primary applicants are Jiangnan University, Nanjing Agricultural University, and China Meat Food Research Center. The research focuses on the technical directions for the isolation, purification, expansion of seed cells, optimization of culture medium composition, culture equipment design, 3D cell molding technology, and cultivated meat technology.

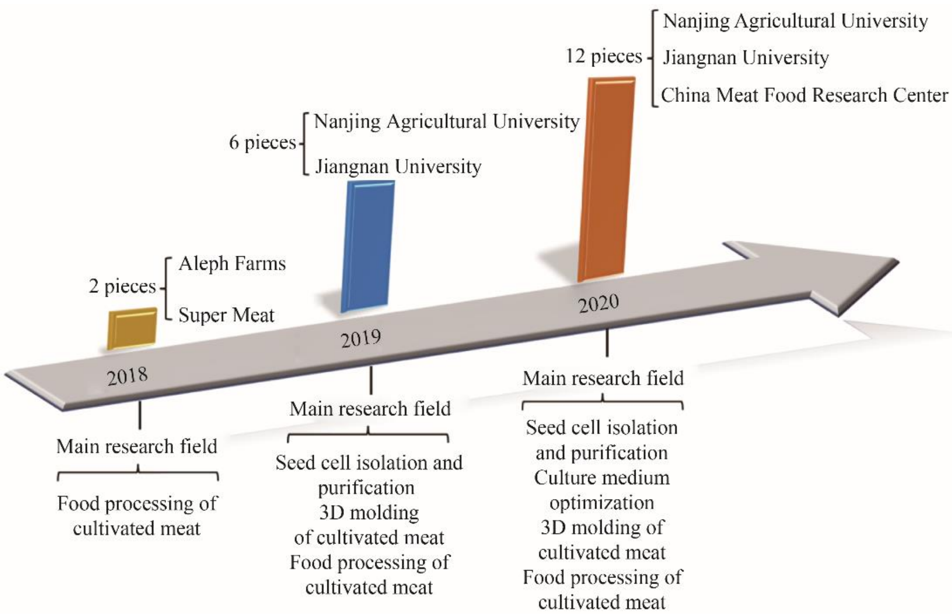

Fig. 3. Patent applications in cultivated meat in China.

In terms of products, Avant Meats is focusing on the development of cultivated seafood, such as fish belly and fish meat. In November 2019, they conducted public tasting tests of fish belly products, thereby initiating the exploitation and optimization of industrial technology for upscaling production. Joes Future Food and CellX focus on research on cultivated meat technology for livestock and poultry animals, which has good commercial prospects and an expected market scale.

4.2 Challenges in the development of cultivated meat technology

4.2.1 Late in industry start and weak in the research base

Compared to developed countries that engaged in research on cultivated meat about 20 years ago, in China, this development has only recently begun. At present, the number of enterprises and research institutions conducting research and development of breeding meat technology is relatively low, and most are in the pre-technology accumulation stage, with a scarcity of publicly available industrialized products. A prerequisite for overcoming the technological barriers of cultivated meat production is to elucidate the fundamental scientific challenges behind it. One of the difficulties is the development of large-scale and low-cost in vitro culture systems for animal stem cells, such as muscle stem cells; the key scientific challenge is the analysis of the process of organism muscle tissue formation and the regulatory mechanism. In the field of biology and medicine, progress has been made on model animals such as mice and humans, but less basic research has been done on livestock and aquatic animals such as pigs, chickens, and fish in the ex vivo culture and regulation of stem cells. Research progress has been made in the fields of biology and medicine for modeling animals such as mice and humans, whereas there has been less basic research focus on in vitro culture and the developmental regulation of stem cells from livestock and aquatic animals, such as pigs, chickens, and fish. Owing to the different cell development characteristics and in vitro culture conditions required for different species, the basic research on the mechanism of muscle tissue development and regulation of stem cell proliferation and differentiation in vitro in livestock, poultry, and aquatic animals is urgently needed to provide a solid theoretical foundation and clear technical routes for breaking through the key technology for cultivated meat.

4.2.2 Limitations in current research and multidisciplinary cooperation

Cultivated meat production requires theories and technologies based on several disciplines including cell biology, synthetic food biology, tissue engineering, fermentation engineering, and food engineering. The concept of cultivated meat production is groundbreaking in the agriculture field and is essentially based on strategies and processes derived from the “building organs in vitro” technology in the tissue engineering field. Although the two technical lines are similar, a significant difference exists in terms of research objectives, expected production scale, and cost requirements. For example, in the medical field, tissue engineering technology combined with stem cell transplantation can achieve individualized and precise treatment of diseases, with the process valuing the biocompatibility of the material and the in vivo function of the cells. However, for cultivated meat, large-scale production and cost-effectiveness are prerequisites for industrialization, as are the flavor, nutrition, and food safety of the product also extremely important. At present, most of the teams engaged in cultivated meat research have a good foundation and strength in a certain discipline and have the ability to overcome a certain key technological barrier in cultivated meat production, but most of the technology development activities follow the inherent ideas and strategies of the discipline, which may not be the best strategy for building a cultivated meat technology system. The failure of meaningful communication and cooperation between the various disciplinary fields, limited by tradition, may lead to the inappropriateness of the single key technologies developed by each, making it difficult to efficiently integrate the technology to enable a complete production system for cultivated meat.

4.2.3 Insufficient research on equipment that restricts the industrialization of cultured meat

Unlike traditional food processing lines, the production and manufacture of cultivated meat require a new dedicated production line with animal cells as the raw material, cell culture medium as the main material, bioreactors as the core equipment, with large-scale, automated, and intelligent features. Currently, two types of animal cell culture products are manufactured using large-scale bioreactors: endogenous and exogenous cell components, such as monoclonal antibodies, cytokines, and cells such as stem cell therapy products. Unlike existing bioreactors, the reactors required for industrial production of cultivated meat need to achieve ultra-large-scale and cost-effectiveness. The product of the cultivated meat is cells, which require stringent conditions for cell culture. The difficulty of this process is in achieving high-density cell culture and maintaining the function of the cells; reliable control processes are needed to monitor the status of cell growth in real-time and the ability to recycle the culture medium to guarantee the quality of the cell product and reduce the production costs. In summary, the relevant research on production equipment and development capabilities and strategies for optimizing processes are important basic conditions for the industrial production of cultivated meat, and the lack of domestic research in this area has limited the progress of its industrialization.

5 Recommendations

Cultivated meat is an important means to realize a sustainable supply of high-quality animal protein. In comparison with international precedents, industrialization technology for cultivated meat with independent intellectual property rights in China still needs to be further developed and improved. With the focus on industrial construction and long-term development, the guidance and support for the cultivated meat industry should be strengthened at the national level; attention should be given to addressing key issues of industrialized production of cultivated meat and formation of a coordinated development mechanism. Additionally, technical efforts should

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be organized to grasp opportunities and establish internationally competitive technology, thus enabling the domestic sale of cultivated meat products in the future.

5.1 Increasing investment in basic research and constructing core technology systems

In 2020, China's National Key Research and Development Program initiated the "Green Biomanufacturing" program to develop "efficient biomanufacturing technology for artificial meat" for the first time and support the research and development of new artificial meat production technology, including plant protein meat and cultivated meat. Although national science and technology programs emphasize the development of cultivated meat technology and encourage researchers to conduct basic and applied research, overall, cultivated meat research is still an emerging niche in China, and many researchers are poorly understood or hesitant to conduct research. To solve the shortcomings in the industrial production of cultivated meat, the authors recommend that basic research be conducted on stem cell growth behavior, muscle tissue structure, nutrition, and flavor characteristics of various types of livestock, poultry, and aquatic animals. Only by fully elucidating the developmental regulation of muscle tissue and the mechanism of flavor and nutrition, are we able to achieve a breakthrough in cultivated meat technology.

To appropriately expand the coverage of cultivated meat-related technologies, it is recommended that funding for cultivated meat research be reasonably increased in subsequent major science and technology projects, key research and development programs, natural science funds, and other national science and technology programs, policy and financial support channels be broadened for cultivated meat research and development institutions and enterprises, and social capital and financial institutions support increased investment and credit in the industry. In view of the technological barriers to cultivated meat production, it is suggested that scientific research units with strong technical foundations and enterprises with research and development capabilities jointly conduct basic research in the field of cell biology and tissue engineering to accelerate the process of research and development of cultivated meat technology systems. Simultaneously, the government should guide leading enterprises, universities, and scientific research institutes to collaborate and participate to form synergy and vitality, to guarantee enthusiasm and efficiently promote industrial development.

5.2 Supporting cross-industry communication and building interdisciplinary research alliances

Technological development of cultivated meat requires synergistic cooperation in multiple fields, such as stem cell engineering, tissue engineering, meat product processing, process scaling, and process control. Only close scientific cooperation among experts and scholars from across industries can break the disciplinary barriers and open up the entire production process to guarantee a substantial breakthrough in cultivated meat technology. The biopharmaceutical industry has developed rapidly in recent years, and the cell therapy field has more mature cell culture, recombinant protein amplification production, and other technologies. The technological advances in related industries provide a technical reference for the industrialization of cultivated meat which should be introduced into cultivated meat production on the basis of extensive discussion and sufficient experimental verification. Superior universities and research institutions should form multidisciplinary joint research centers working on cultivated meat technology, which should include experts and scholars engaged in research on muscle development and diseases, stem cell biology, tissue engineering, amplification processes, meat processing, as well as technology developers of relevant enterprises. Through this multidisciplinary group of experts, collaborative research and development can take place. Moreover, comprehensive communication and deepening demonstration of the entire process technology of cultivated meat production from multiple professional perspectives will accelerate the breakthrough of complex technological barriers in the industrialized production of cultivated meat. Simultaneously, it is also conducive to clarifying the key control nodes and quality control standards in the upstream, middle and downstream processes of cultivated meat production, which can provide the basis for the formulation of cultivated meat regulatory policies and quality management system.

5.3 Strengthening the cooperation of academia and enterprises to accelerate result transformation

Universities and research institutes have conducted extensive research on policy regulation, safety evaluation, and technology development in cultivated meat, using appropriate basic research, advanced instruments, and experimental platforms. However, knowledge on up-scaling production is lacking. In contrast, cultivated meat enterprises have independent development departments that are primarily engaged in the development and optimization of production processes and rarely involved in basic research. Through close cooperation between universities and enterprises, with their basic and application perspectives, respectively, and unique advantages, their joint research and development will enable the domestic industrial development of cultivated meat.

With a focus on long-term development, and acquiring the basic conditions of cultivated meat research and development and large-scale production, the authors recommend that the university–enterprise cooperation model be maintained, the benefit distribution mechanism be clarified, the coverage of industry–university–research be broadened, and deeper cooperation in technology research and development of the cultivated meat industry be initiated through the transformation and application of scientific and technological achievements, and personnel training. By complementing the advantages of multiple parties and integrating technologies, optimized conditions are created for the development of the cultivated meat industry. An integrated production line of cultivated meat can be constructed at an appropriate time to demonstrate the achievement of transformation and promote the industrialization process of cultivated meat. Ongoing research by universities and research institutes may provide solutions to emerging technical problems encountered in large-scale production to enable the continuous optimization of the production system, gradually grow the scale of the industry, and steadily improve its development level.

5.4 Focusing on consumer demand to develop specialized cultivated meat products

The focus of current research and development in cultured meat is on upstream cell culture, but not on the food properties of cultured meat, i.e., texture, taste, and aroma. It is worth emphasizing that meeting the nutritional and taste needs of consumers is the starting and return points of the entire industry's scientific research activities. As a novel food product, consumers' awareness and acceptance need to be improved. Considering the significant differences between Chinese and Western food cultures, replicating foreign cultivated meat production strategies and technologies may not produce meat products that are pleasing to Chinese consumers.

The authors propose that consumer publicity and research on cultivated meat be conducted through multiple channels and angles to improve public acceptance of cultivated meat and obtain effective feedback on consumer needs and suggestions. Furthermore, the dietary habits and culture of residents should be wholly considered, and cultivated meat products that adapt to the needs of national nutritional composition and diversified flavor and taste should be developed. Finally, products should be developed to suit different dietary needs and sensory taste characteristics of foods for consumers, to improve the value of cultivated meat products.

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