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Future of Cultured Meat Production: Hopes and Hurdles

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Rising environmental issues, animal welfare concerns, and a vulnerable food supply chain demands an effective and long-term solution for food security in the future. All these challenges encourage the researchers to find more reliable and clean ways of food production such as cultured meat. This process involved the production of animal meat in the lab using large bioreactors without raising animals. Cultured meat production is widely accepted among animal rights activists, and it can solve the issues related to conventional farming such as excessive use of the land resource, animal slaughter, foodborne diseases, and antibiotic resistance. Despite all these advantages, it is facing some serious challenges, which include technical, social, and ethical limitations. Extracting specific cell lines, developing animal-free growth media, upgradation of bioreactors, developing desired scaffolds, and changing the public perception towards lab-grown meat are fundamental challenges that need to be discussed. Major technical hindrances include the production of serum-free growth media, the development of economical and sustainable cell lines, and the upgradation of bioreactors to produce meat at the industrial level. Apart from technical issues, social acceptability is another big challenge in the development and marketing of cultured meat. Mass awareness campaigns through electronic and social media along with the provision of incentives to local farmers can address this challenge. This review intends to summarize both technical and social challenges that are halting the availability of cultured meat in the market and suggests some feasible recommendations to overcome these obstacles.

1. Introduction

The human population is increasing continuously and is expected to exceed nine billion by 2050. Ever-increasing human population has created huge pressure on existing food resources that is a looming threat to food security. Animals are the major source of human food after plants, comprised of essential nutrients mandatory for human nourishment. Protein from animal sources is 40% of total protein consumption now and will continue to increase with the increasing population (Stoll-Kleemann & O'Riordan, 2015). According to the Food and Agriculture Organization (FAO), more than 56 billion domesticated animals are reared and killed for human consumption annually and food demand will be increased by 70% in 2050, so protein consumption will also increase (Tobler et al., 2011). Escalating demand for animal-source products put pressure on the livestock sector, which needs to attune fast to meet such demand and that would not be achievable without branching out yield and increase of crop agriculture. However, the lack of available new

land for expansion of crop production forbids a 'horizontal' augmentation of current modes of production and forces the meat sector to search for alternative resources (Steinfeld et al., 2017).

On the other side, current livestock production systems are surrounded by a variety of issues including pollution, habitat destruction, biodiversity, animal welfare, and greenhouse gas emissions. If we rely on our livestock farming system to meet that enhanced requirement of protein, then it must produce a huge quantity of high-quality and affordable meat by using an environment-friendly system (Bhat et al., 2017). However, the majority of livestock production is under the factory farming model, where the major focus is the efficiency of the system to produce maximum product rather than its environmental effects, minimizing the use of antibiotics, and animal welfare (Aleksandrowicz et al., 2016). Greenhouse gases (GHG) are not the only factor associated with livestock production systems to affect climate change, but carbon dioxide ("CO^2) emissions also contributed that resulting from fossil fuel burning in tractors for maintenance of crops' lands (Dawson & Hilton, 2011; Gerber et al., 2015; Reisinger & Clark, 2018). The direct effect on human health is also reported by such kinds of intensive livestock farming as both workers and those living in the vicinity of an intensive livestock farm experience high levels of respiratory problems, including asthma (Ilea, 2009). The world is in search of systematized ways of protein production to assist the expanding world population while satisfying current challenges, such as environmental and animal welfare concerns (Aiking, 2014). Among the solutions, cultured meat is proposed as a viable substitute for consumers who do not wish to change the composition of their diet and a source for reducing the pressure on the livestock production system to ensure animal welfare (Kadim et al., 2015; Moritz et al., 2015; Post, 2012).

Cultured meat is the manufacturing of meat in a laboratory by employing tissue culture technology. The basic idea of cultured meat is to produce animal meat without raising the live animal. In this technique, stem cells are taken from live animals and planted into specific culture media having the necessary nutrients required for cell proliferation and growth (Bhat et al., 2015)(Fig. 1). On basis of theoretical knowledge, we have up until now, it is considered that cultured meat is much better as compared to conventional meat production as it can potentially reduce environmental challenges and can address the issue of animal welfare by reducing intensive livestock farming. Every year, billions of animals are being slaughtered to satisfy the growing human hunger for meat, bringing huge suffering to sentient beings. Thus, developing more feasible and cost-effective methods could help humanity to find more humane and clean ways to produce meat. Cultured meat could transform meat production providing a much more sustainable and environmentally friendly substitute for conventional meat production. Despite its obvious advantage over conventional meat production, there are several challenges and limitations to cultured meat production and its commercialization (Alexander, 2011; Zuhaib Fayaz Bhat et al., 2017; Bryant & Barnett, 2020). The major challenge in the production process of in vitro meat is the use of foetal bovine serum (FBS) as growth media during cell proliferation because FBS has the necessary nutrients and proteins for muscle cell growth. FBS is obtained by slaughtering cattle during pregnancy, which is considered an inhumane act and cruelty to animals. Apart from this, FBS is also expensive, as it constitutes 80% of the total production cost for cultured meat (Mattick et al., 2015). Social and religious limitations are other big challenges to the commercialization of in vitro meat. The first time, cultured meat was produced in 2013 and got much popularity among the media and scientific community followed by a sudden rise in the number of companies investing in the production of cultured meat. At present 32 companies are working on cultured meat with more focus on beef and poultry meat production but still, it is facing many social and ethical barriers that are major hindrances to the acceptability of cultured meat.

It seems that cultured meat will be adopted gradually in near future and it will open new horizons in the meat production industry (Hocquette, 2016). This review intends to address the questions that why there is a need for culturing clean meat in near future and how it can help humanity to cope with environmental challenges and address animal welfare concerns.

2. Cultured Meat: The meat of the future

After the industrial revolution and human-eating habits also revolutionized, human hunger for meat has increased manifold. There is an interesting phe-

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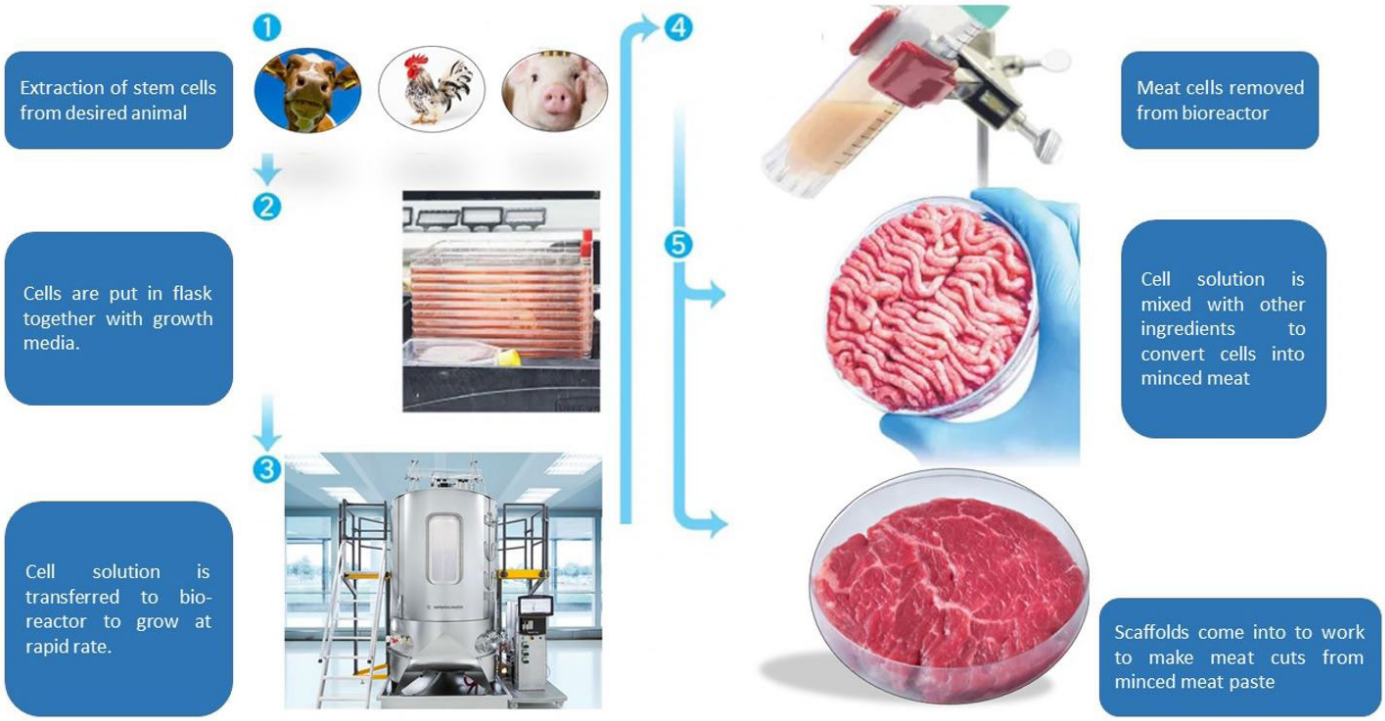

Figure 1. Stepwise illustration of the process involved in the production of cultured meat in the lab.

nomenon related to economic stability and meat consumption. Meat consumption is higher in developed parts of the world and its consumption is gradually increasing with the rise of the middle-income class across the globe. Keeping this trend in mind, developing an efficient meat production system is mandatory to fulfil future meat demands. During the last decades, the intensive factory farming model followed by escalating meat demands is on the rise. Unfortunately, this intensive farming gave birth to several environmental, health, and animal welfare issues. Secondly, the burgeoning human population is putting more pressure on limited land resources that will be insufficient to meet human demands. It is a need of the hour to develop such an efficient mechanism that can potentially help humanity to produce enough food by utilizing minimum resources (Post et al., 2020).

Addressing this growing challenge requires a dramatic change in meat-eating habits by shifting to a vegetarian lifestyle but such a major change in food habits is unlikely to happen in near future. Some plant-based meat substitutes have also been developed to discourage the increasing demand for animal meat, but this strategy too did not work well. The only option left is to find more effective, humane, and cleaner ways to produce meat (Hocquette, 2016). Producing meat in the lab without harming animals is an innovative technique as compared to conventional methods of meat production. Moreover, conventional meat production is a very lengthy and laborious process involving different stages such as breeding animals, raising them in specific environments, feeding, and then killing the animals. The whole process of conventional animal farming is much laborious, requires more resources, and violates the universal standards of animal welfare. In contrast to this, cultured meat is grown in the laboratory by using desired cell sample under controlled conditions through modern techniques of biotechnology (Laestadius & Caldwell, 2015). This technology reduces time and uses very limited resources to produce a huge quantity of meat. To sum up, lab-grown meat will likely offer huge benefits regarding environmental impact, animal welfare, and human health.

3. Animal Welfare Prospective

Animals provide food to humans including meat. Just as humans, animals deserve benefits. Therefore, humans should have a moral duty to make sure the com-

fortability of animals. In the meat-based production sector of livestock, animal welfare is highly important to improve productivity, quality of meat, and economic returns. Concerns about animal welfare are on the rise globally. In research areas, animal welfare subject has made its significant place; even this subject is now in the media and politics as well. Animal welfare has been included in the major agendas of OIE for more than a decade because of its connection to animal health management and food safety, which are linked to human health. So, animal welfare is of supreme importance and cannot be neglected in any case (Madzingira, 2018). On the other hand, the outcome of conventional production has caused many problems, especially with the high concentration of livestock. Over the past 20 years, world meat production has been increasing mainly in the intensive livestock sector (Ilea, 2009).

There is growing and highly notable concern about animal welfare in meat production (Broom et al., 2019). If we consider the pig production system, which is a huge industry for meat production is surrounded by many welfare concerns. Most of these issues are related to close confinement, lack of enrichment, and breeding for the traits that are responsible for intensive production. Ultimately, the constraint for improving welfare is usually set by certain housing, pen design, feeding method, or genetics. But these factors cannot easily have changed and will grow more with an increase in demand (Pedersen, 2018). Similarly, the broiler production system is full of welfare issues which include their feeding methods, overcrowding, humidity issues, lightning schedule, and capturing method (Filho et al., 2014). In beef production, many welfare issues are present among smallholder and commercial farmers including draught power, poor housing conditions, poor transport conditions, ritual slaughter, tradition, social customs, and beliefs (Ndou et al., 2011). All welfare issues are related to intensive livestock production as demand is increasing no way is found except to increase the number in limited space and focus on traits of intensive production for breeding (Pedersen, 2018). That increasing demand is requiring an alternate way of meat production rather to put the whole burden on animals and damage their welfare (Ilea, 2009). That alternate way of meat production is cultured meat that requires less energy, low GHG, low water, and low land requirement with excessive production. This will not only provide a clean way of production but also reduce the burden on the animal sector and minimize the welfare concern of domestic animals (Lynch & Pierrehumbert, 2019).

4. Challenges to the production of cultured meat

4.1 Technical challenges

Despite the rapid progress in the technology of in vitro meat production, there are a few challenges in the production of synthetic meat such as procurement of cell lines, high production cost, culture media from animal sources, and limited scale of production. This topic intends to discuss the obstacles in the way to delivering synthetic meat from the lab bench to the dining table (Bhat et al., 2017).

4.1.1 Obtaining specific cell line

In recent days, cell lines are mostly used in the biotech business and research for the production of various biological organisms and products such as viruses and proteins. In the process of cultured meat production, stem cells are used as they can divide, proliferate, and differentiate into different types of organs or meat. In this procedure pluripotent stems are needed that can be obtained from different parts of the animals including muscles, liver, and adipocytes. Apart from this, pluripotent stem cells can also be obtained from embryos or separated from fibroblasts (Z.F. Bhat & Bhat, 2011; Datar & Betti, 2010). The process of developing suitable stem cell lines is very costly and time-consuming, as it requires advanced gene delivery technology. It has been tested to introduce specific genes to obtain desirable traits like fast muscle production. The conventional method of introducing genes through viruses has a low transfection yield and it limits the scalability of meat production (Dilworth et al., 2015). Secondly, poor characterization of a cell line can badly affect meat quality control. During the rapid division of cells, the genetic content of cells becomes highly unstable. For example, during DNA replication, any variation, insertion, or deletion can cause serious structural and functional changes (Dilworthet al., 2015).

4.1.2 Preparation of scaffolds

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During cultured meat production, the scaffolds are used to anchorage the cell and support the physical activities of meat including stem cell differentiation. Scaffolds are important during this process as they assist in nutrient, oxygen uptake, and help the cells to diffuse the metabolic waste products. So, different types of scaffolds have been designed by tissue engineers based on the previous knowledge of organ regeneration (Gaydhane et al., 2018; Hocquette, 2016).

Commonly, two types of scaffold materials are being used which include naturally derived or synthetic. Chitosan and cellulose are natural scaffold material, and it has many benefits over synthetic material, as they are biodegradable, safe, and economical. However, they exhibit much variation in their characteristics including the extent of polymerization and molecular weight. While, synthetic scaffolds are synthesized and designed according to desired properties such as porosity and ligand availability (Bhat et al., 2017). As the production of synthesized scaffolds is a complex process, it has a higher production cost and it is harder to get regulatory approval for these kinds of scaffolds (Kadim et al., 2015). The hybrid model of scaffolds including naturally derived scaffolds as the primary material and a small quantity of synthetic material could solve the issue of biomaterial scaffolds. Apart from this, advanced production methods like 3D printing can be implanted to print the desired scaffolds for meat culture (Noor et al., 2016).

4.1.3 Development of animal-free growth media

For large-scale production of cultured meat, cells grow and differentiate rapidly; the growth media should be able to provide enough supply of nutrients such as glucose, amino acids, and vitamins (Godfray et al., 2018). One of the reasons behind the high production cost of cultured meat is expensive commercial growth media. It is widely considered that cultured meat is animal-free meat but in reality, its production involves the animal source growth media (foetal bovine serum). This serum contains all of the vital nutrients and growth factors that are not easy to prepare and find an alternate animal source growth media (Noor et al., 2016; Post, 2012; Tuomisto, 2019). Some researchers are finding ways to increase the production of certain proteins like growth factors at cheaper prices through genetically engineered microorganisms, fungi, and plants to replace the animal source of growth media. Some research groups have successfully developed growth media free from serum such as serum-free media manufactured during a study that supports the growth of bovine myoblast but not as fast as the media with serum content (Z.F. Bhat & Bhat, 2011).

4.1.4 Upgradation of bioreactors

Production-scale bioreactors which are available commercially are typically 1–2 m3 in working volume for cell culturing, although larger reactors up to 10–20 m3 can be custom-built (Flickinger et al., 2010), still, their size is much smaller than microbial reactors, which can be 200–2000 m3. Many reasons are behind the use of smaller reactors for cell culturing as multiple smaller units can provide flexibility and offer proper control and management of contamination. So it is very critical to address these challenges regarding the type of reactors for large-scale cultured meat production (Zhang et al., 2020). Currently, laboratories are the only production sites for cultured meat as it is at a high cost and still facing difficulties to commercialize. A major reason for this is that current artificial meat products do not compete with the quality of real meat in a cost-effective and resource-efficient way. Therefore, it is now important to satisfy these needs with real colour, nutrition, fragrance, and taste e.g., haemoglobin addition in artificial meat is necessary to give natural colour. Haemoglobin sources are animal blood or plant tissue, but extracting from them is time-consuming and not cost-effective (Zhang et al., 2017).

4.2 Lack of financial support for cellular research

Most of the research, to produce cheap cultured meat at a large scale, is still needed to be done which specifically involves the selection of cell lines and the development of animal-free growth media. Until now, there are no specialized institutes or scientific disciplines to entirely focus on research related to cellular agriculture. Most of the studies related to cultured meat are conducted as an isolated projects and not linked to academic interests. Cultured meat can be produced only in lab conditions using expensive materials and techniques adapted from other related fields of biotechnology. To find a long-term solution

to address the challenges related to cultured meat production, separate research funding and opportunities are needed for only the development of cellular agriculture (Dolgin, 2019).

4.3 Animal welfare concerns regarding growth media

The purpose of culture media is to support cell growth and division by feeding them essential nutrients such as amino acids, sugars, vitamins, and minerals. At present, foetal bovine serum (FBS) is a key component of most growth media. This ingredient is obtained from the blood of the foetus by slaughtering the pregnant cow, which is an inhumane practice. Therefore, it raises severe concerns about animal welfare. Although no animals are involved in the production of meat during this process still needs animal source culture media to grow the meat cells. An ideal growth media should not involve animal products. Some studies demonstrated that growth media can be produced from fungi and plants but these growth media are not as effective as FBS (Slade & Bauen, 2013).

4.4 Public perception about cultured meat

It is a common perception, that anything natural is good while anything unnatural is bad for human consumption. It is just an assumption and has nothing to do with reality. Something can be natural and bad, and at the same time, an unnatural thing can also be good (Schneider et al., 2013). There is a strong relationship between natural and unnatural. Everything and every process are already present in the universe, and we just need to discover that. In ancient times, there was no intensive animal farming, in that way animal farming during those times was an unnatural process. So, the term natural and unnatural is very ambiguous, especially in regard to the production of cultured meat (Takala, 2004). Although cultured meat is grown in a lab artificially, the result is just as original as orthodox meat and possesses low health risks as compared to conventional meat. In reality, since it is synthesized in a controlled manner, cultured meat is less likely to comprise harmful by-products, unhealthy fats, and food-borne pathogens than its conventional counterpart (Lynch & Pierrehumbert, 2019; Woll et al., 2019). Secondly, some people raise questions about the ethical standing of cultured meat. As cultured meat requires FBS as growth media which is an animal-derived product and involves the killing of pregnant cows and foetuses, and hence poses a serious ethical challenge. To achieve this goal, the development of animal-free culture media is mandatory. Apart from cultured media, some scientists are afraid that widespread acceptance of cultured meat will promote cannibalism as after the development of this technique any kind of meat can be grown in the lab by using the cell line. This is also a serious ethical challenge that requires proper legislation regarding the production of cultured meat around the globe (Woll, 2019).

5. Strategies to overcome these challenges

In the modern world where the population is increasing due to advancements in medical sciences, the needs of the growing human population are also increasing. In such a situation of competitiveness in life, cultured meat is inevitable. China and India with a massive increase in population appealing for the alternate source of meat because people of these countries are raising from the poverty level rapidly (Beinhocker et al., 2007). When there is a rise in the poverty level due to the betterment of the economy of the country, people become more able to afford better nutrition, which ultimately increases the demand for meat. The conventional agriculture system is unable to fulfil the demands of such growing populations and shortage of food, inflation in prices of food, and uncontrolled damage to the environment could be the consequences. Such destructive effects can be avoided by realizing the inevitability of cultured meat production and if it becomes a source to satiate the global nutrition needs. To make the cultured meat sector a sustainable source there is a need for more aggressive development if we want to avert food and agriculture, and environmental crises.

5.1 Role of media

Consumer interest is being developed in food ethics, which is linked with different cultural values. Therefore, the compatibility of food with the lifestyle of any human being matters a lot in any society. People, who are not choosy about their food, even reject some kinds of food due to social, cultural, and religious unacceptability. Here come the media, which can play a significant role in the opinion-making about any

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kind of food including cultured meat. There is a dire need for understanding media coverage about the culture's meat authorities (Goodwin & Shoulders, 2013). To date, the coverage of the media remained about highlighting animal farming issues and telling about the benefits of cultured meat but it can make a huge difference when cultured meat is present at the market for providing not only an alternate option but with proper nutritious value (Post et al., 2014). Media coverage regarding a disease outbreak, antibiotic use, and inhuman handling of animals raised many concerns about intensive livestock farming. Moreover, global warming impact and the increasing human population should be highlighted to spread awareness concerning alternate meat sources like cultured meat (Springer et al., 2014).

A survey of Dutch consumers observed that, when asked the question, if they were ready to try cultured meat once it gets accessible, being given information about its environmental benefits triggered positive answers to increase from 25% to 43%, a near-doubling compared with only basic information regarding the technology itself. Another online survey conducted on social and news media sites has found that 70% of consumers are willing to try cultured meat once it becomes available. Therefore, these surveys highlight the importance of the media's role in spreading awareness and information related to this new technology could help to change the public perception in near future (Tuomisto, 2019).

5.2 Involving conventional farmers in the production process

In many countries, agriculture is the major sector and most of the population in developing countries is directly or indirectly involved in this sector. In East Asia, 62% population is involved in the agriculture sector. Even in Europe, 4.4% of employment is related to agriculture (Eurostat et al., 2017). In the case of the cultured meat sector, no doubt that there will be the creation of new jobs for people, and a completely different skill set will be needed for that kind of job as compared to the conventional agricultural or livestock farming skills. In such a case farmers may end up having a small share in the market and be financially unstable (Bonny et al., 2015). In history, we can see many examples when one sector is revolutionized with some innovation many people having conventional mindsets lost their businesses and jobs. For example, Luddites of the textile sector in England damaged the equipment and machinery to go against the job losses that new technology created in the 19th century. The point about joblessness can be summarized through allegory, according to which an economist once visited the construction place and raised the question. Why are hundreds of workers using shovels instead of modern machinery? The supervisor replied that is how jobs are created, the economist said if the purpose is job creation, then give them even spoons instead of shovels (Tanner et al., 2015). There are no doubt innovations like this create job losses instantly, but that's how betterment comes up as the society in which we are living with great advancement in the technology and many other sectors couldn't be possible without such innovations which have created many jobs for some, and some lost them. However, there is a middle ground in this regard, which is the involvement of local farmers in the cultured meat sector. As the cultured meat sector is not going to be established in a single night, there is a transition time for switching from conventional livestock farming to cultured meat farming; which is more sophisticated and may come up as a more profitable business. There is a dire need to spread awareness among not only the public but also involving the local farmers and attract them by designing a profitable business model in this sector.

5.3 Research funding and legislation

The governments and research organizations should allocate more funds for agricultural biotechnology to accelerate the research progress in the development of cultured meat. Research should emphasize producing optimal cell lines, animal-free culture media, up-gradation of bioreactors, and innovating the existing techniques for producing the intricate muscle tissues. After the sustainable and economic production of lab-grown meat, it will require new legislation and regulatory framework in every region of the world, where production takes place. It also requires the involvement of political and legal organizations to design regulations for the production and consumption of lab-grown meat.

6. Conclusion

Conclusively, cultured meat offers a hope that humanity can become less dependent on animals for meat, thus decreasing the environmental and health impact of animal production. There are still major scientific obstacles to overcome including the development of quality cell lines, cos-effective, and animal-free growth media production, designing bioreactors for producing tissue layers at a large scale before cultured meat can become a common food product. Modern technology in genetic engineering, biomaterial design, and sequencing methods can provide real technical solutions to all these issues. We can fulfil the needs of the increasing population, address animal welfare concerns and make the environment clean and healthy through cultured meat production.

Conflict of interest

The authors declare no conflict of interest.

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