Food Research 7 (2) : 42 - 51 (April 2023)
Journal homepage: https://www.myfoodresearch.com
FOOD RESEARCH

REVIEW

Review on cultured meat: ethical alternative to animal industrial farming

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Article history:
Received: 1 October 2021
Received in revised form: 23 November 2021
Accepted: 8 March 2022
Available Online: 17 March 2023

Keywords:
Cultured meat,
Lab-grown meat,
Tissue engineering,
Food technology,
Food bioprocessing

DOI:
https://doi.org/10.26656/fr.2017.7(2).772

Abstract

It is estimated that around 8% of the entire world population identifies themselves as vegetarians. That leaves us with statistics of more than 90% of the world's population prefers a meat-based diet. Now with the alarmingly increasing population of over 7.8 billion, the demand for meat is skyrocketing. Due to the high demand, factors like land, water and greenhouse emission are becoming unsustainable. Even after taking all these concerns into account, why is it so difficult for us to eliminate/reduce meat from our diet? How is the future generation going to satisfy their meat cravings? However, through recent research, it seems there is an alternative, a solution to all these concerns, cultured/ lab-grown meat. Cultured meat is meat produced by in vitro cell culture of animal cells, instead of from slaughtered animals using various tissue engineering techniques. This in-vitro meat technology is still at its elementary stages but shows great potential in curbing the problem of livestock overcrowding and its impact on the environment. Cultured meat seems to promise a sustainable and reliable alternative for its consumers. This review aimed to provide an elaborate comprehension of the entire process of the production, processing and commercialization of cultured meat, and also provides an insight on the possible obstacles it encounters, especially overcoming ethical conundrums and social prejudice.

1. Introduction

In layman's terms, cultured meat A.K.A lab-grown meat is produced through the cultivation of animal cells in a controlled environment, instead of animal slaughter. Going back in time, it is known that the first mention of cultured meat dates back to the 1950s when a Dutch scientist, Willem van Eelen had independently thought of using tissue culture for the generation of in vitro meat. After a few decades, in 1998, Jon Vein filed a U.S. patent for the "production of tissue-engineered meat for human consumption, wherein muscle and fat cells would be grown in an integrated fashion to create food products such as beef, poultry and fish." Nevertheless, over these decades, the human population has more than doubled and the amount of meat produced has quadrupled i.e., 355 million tonnes each year for which around 24000 animals are killed every hour that is 75 billion animals per year. In future, it is estimated that the demand for meat is going to further escalate to reach 455 million tonnes by 2050 (Desai, 2020).

Human beings have come a long way through evolution and meat is seemed to have played an essential role in it. Meat is a high-quality energy-dense food with a lot of calories and protein. Since it was easier and more efficient to digest meat than the plant-based diet that took a longer period of time for digestion, our evolving brains could capture the extra energy needed for its growth. But now humans still continue to prefer a meat dependent diet, mostly not because human needs it but much more because they have learnt to savour it. Human's attachment to meat led to the advancements in food technology that affected the meat industry. The profile of meat was improved for people in the aspects of safety, quality and product stability. In 2002, the first edible lab-grown meat sample is produced from cultured goldfish cells (Bhat and Fayaz, 2011). A few years later scientists from the Netherlands had managed to grow meat in the laboratory using the cells from a live pig and the first lab-grown beef hamburger at Maastricht University, Netherlands, was consumed at a press event in London, England (Post, 2013). Over the next few years, many start-ups emerged paving the way for cultured meat to market trying to reduce the cost of production and make its market price comparable to that of conventional meat. On 2 December 2020, the

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eISSN: 2550-2166

Singapore Food Agency approved the "chicken bites" produced by Eat Just for commercial sale. It was the first cultured meat product to have passed the safety review of a food regulator (Carrington, 2020).

Now looking into the causative factors of surging demand for meat it is found that population growth, urbanization, technological advancement, economic growth and thriving markets contribute majorly to the increase in demand for meat. Apart from nutritional and palate-preferred needs, meat also seems to play a social role. As developing countries like India, China and Russia are moving higher on the scale, it shows an increased demand for more luxury products such as meat and other animal products from such consumers. Worldwide, 30% of the land surface is used for livestock production with 33% of arable land being used for growing livestock feed crops and 26% being used for grazing. About 70% of the freshwater use and 20% of the energy consumption of mankind is directly or indirectly used for food production, of which a considerable proportion is used for the production of meat (Bhat and Fayaz, 2011). To meet such demands, efficient and cheap production methods need to be implemented. Hence, the herding of animals in confined spaces in unfavourable conditions is practised. The adaptability of the animals is not high enough to cope with these unnatural conditions, and high-stress levels are observed, resulting in disease, abnormal behaviour and death. Another important issue is that of animal disease epidemics and a more serious threat is posed by the chicken flu, as this can lead to possible new influenza epidemics or pandemics, which can kill millions of people. As a consequence, in this day and age researchers, philanthropists and industrialists preferably invest their time and money into the development of technology and market for cultured meat. This review focused on the various elements including from the production to manufacturing of cultured meat if cultured meat is actually a better alternative to conventional meat and how far are humans as a race from actualizing this concept sustainably into our lives.

2. Lab-grown meat: a solution to our meat problems

Conventional meat has been a major source of protein ever since Homo sapiens began hunting, however, as humans evolved the nutrition factor became subsided and comfort and taste became primary aspects of meat. Hence, the invention of cultured meat was not only a breakthrough for tissue engineering and stem cell research, but it proves to be a necessity. Glancing over a few of the major disadvantages of conventional meat, the first downside is animal slaughter (over 130 million chickens and 4 million pigs are slaughtered every day for meat) (Carrington, 2020), population explosion is an initiating factor for most of the world problems, in this case as the number of people in a country increase so does the demands that leads to excessive breeding of livestock in congested factories that leads to contamination issues that could be cause for pandemics and epidemics and some nutrition-related diseases, gastro-enteritis and food poisoning due to aggressive use of antibiotics and artificial growth hormones (Manyi-Loh *et al.*, 2018). Even in order to accommodate these demand surges, resources are required. By weight, 60% of the mammals on earth are livestock, 36% are humans and only 4% are wild. About 30% of the land surface is used globally for livestock production. For animal rearing, a huge area of forest is being devastated. About 70% of the freshwater and 20% of the energy consumption of mankind is directly or indirectly used for food (meat) production, such events lead to a cascade of consequences as the livestock sector contributes 18% of the anthropogenic greenhouse gas emissions and 37% of the anthropogenic methane emissions to the atmosphere worldwide. Cultured meat may not eliminate all these issues entirely but reduces its effect significantly which should add a few extra years of sustenance to human life on earth (FAO, 2012). Cultivated meat is cruelty-free and vegan-friendly. It is cultivated in bioreactors that avoid bacterial contamination from animal waste and the overuse of antibiotics and artificial growth hormones in animals. Cultured meat provides increased nutrient fortification, individually customized cellular and molecular compositions, and optimal nutritional profiles. Since it does depend on animal resources like land surface, freshwater and the energy consumption is significantly minimised. Reduction in land use opens the prospect for land reforestation and restoration of endangered species. The small scale of current cultured meat production requires a relatively high use of energy and therefore carbon emissions. But once scaled up its manufacturers say it will produce much lower emissions and become environmentally sustainable. Research shows cutting meat consumption is vital in tackling the climate crisis and some scientists say this is the best single environmental action a person can take (Treich, 2021).

3. Production of cultured meat

3.1 Tissue engineering and its role in cultured meat production

Tissue engineering (TE) is an interdisciplinary field that applies the principles of engineering and the life sciences toward the development of biological substitutes that restore, maintain, or improve tissue function. TE finds its application in various fields of technology and science, and cultured meat, since cannot

https://doi.org/10.26656/fr.2017.7(2).772

be produced through biopsies for a larger crowd and is one of the products that implement various TE techniques for its development. TE is now mainly used for regenerative medicines in various types of tissues and organs, also it finds its heavy application in *in-vitro* model systems for drug-screening pressure sores and in vivo transplantation to treat muscular dystrophy and muscular defects. It is only obvious that it finds its utility in the production of in-vitro cultured meat. Structurally, meat is an exsanguinated and dehydrated product of the musculoskeletal system that can be formed of a number of tissues including skeletal muscle, bone, connective tissues, blood vessels and nerves. It is predominantly skeletal muscle that is bound to the bone via tendons and connected to each other via a network of connective tissues of varying compositions but predominantly composed of collagen. There are three processes by which skeletal muscle is formed: embryonic myogenesis, adult skeletal myogenesis and muscle regeneration. *In vitro* skeletal muscle tissue engineering aims to mimic the regeneration of muscle after trauma and/or embryonic myogenesis. Although cell type and maturation pathways may differ, the end goal is to obtain a terminally differentiated cell capable of proliferating and differentiating into muscle fibres. A cell source that can proliferate indefinitely and also differentiate into functional skeletal muscle tissue is required. These cells need to be embedded in a 3D matrix/scaffold that allows for muscle growth, while continuous delivery of nutrients and release of waste products. Finally, muscle cells need to be conditioned adequately in a bioreactor to get mature, functional muscle fibres (Arshad *et al.,* 2017).

3.2 How is cultured meat made?

The basic procedure outline of lab-grown meat is not very different from cell culture methods. It starts with the choice of an animal cell, which is then cultured using the appropriate growth medium that contains nutrients that promote its growth and survival. Edible scaffolding is used for the growth of culture as it begins to expand and mechanically stretches them, 'exercising' the muscle cells to increase their size and protein content. Finally, cells are allowed to divide and expand until ready to be cooked, seasoned and consumed as boneless meat.

3.2.1 Source and type of cells

Meat, or skeletal muscle, contains about 90% muscle fibres, 10% connective and fat tissues and 0.3% blood. Skeletal muscle tissues can be generated in scaffolds by co-culturing muscle cells, endothelial cells (ECs) and ECM-producing supporting cells but lack fat and blood components. In order to recapitulate the fat composition of the native skeletal muscle tissue, it should be generated from adipocytes. Generating fat *in-vitro* may require intensive research, as current adipose tissue engineering research focuses on fat outside the muscle and uses human and mouse models that are inefficient for ruminant animals. As for blood components, with the exception of fish, the majority of the hemoproteins in meat stem from myoglobin found inside muscle fibres. While vascularization has an important role in tissue development, cultured meat may be simpler to produce without them, as blood vessels may not be an essential component of meat taste or texture.

Pluripotent stem cells would be the ideal kind to develop all the tissue found in meat but due to ethical issues, pluripotent cells like embryonic stem cells are controversial to be used in research. So the alternative to this is induced pluripotent stem cells which have the same favourable characteristics as immortality, high proliferative ability, serum independence and easy differentiation into tissue (Gaydhane *et al.,* 2018).

Different types of stem cells are required in developing in-vitro meat, among the stem cells most preferred ones are myoblasts or satellite cells which are mostly responsible for muscle regeneration and repair. Satellite cells are able to easily differentiate into myotubes and mature myofibrils when cultured cells reach maximum numbers and also have better regeneration capacity. Myosatellite cells have been successfully isolated from the skeletal muscle tissue of several species used for meat production including cattle (Dodson *et al.,* 1987), chicken (Yablonka-Reuveni *et al.,* 1987), fish (Powell *et al*., 1989), lambs (Dodson *et al.,* 1986), pigs (Blanton *et al*., 1999; Wilschut *et al.,* 2008), and turkeys (McFarland *et al.,* 1988). Isolation usually involves the use of proteolytic enzymes to separate the myosatellite cells from other tissue structures (Danoviz and Yablonka-Reuveni, 2012; Kadim *et al.,* 2015).

Other potential cell types are adipose tissue-derived adult stem cells that are derived from subcutaneous fat in the adipose tissues, and get transdifferentiated to myogenic, osteogenic, chondrogenic, or adipogenic cell lineages and have high immortality and undergo a rapid transformation for long-term culturing (a major concern being their tendency towards malignant transformation in long-term culture). Mature adipocytes could dedifferentiate in vitro into a multipotent pre-adipocyte cell line known as dedifferentiated fat (DFAT) cells, which have the ability to transdifferentiate into skeletal myocytes. It may be desirable to co-culture adipocytes with myofibrils in order to enhance the texture, flavour and tenderness of cultured meat by effectively increasing the intramuscular fat (Gaydhane *et al.,* 2018).

For developing ECM, a supporting cell type whose

https://doi.org/10.26656/fr.2017.7(2).772

main role is to secrete ECM is required. Fibroblasts and myofibroblasts present be the best choice since the majority of skeletal muscle tissue ECM is deposited and remodelled by fibroblasts. These are simple to isolate and grow and have a short cell cycle. They were shown to promote vascularization and muscle development. However, these isolated cells are usually not well defined, while being unfavourable for co-culturing and difficult to control the concentrations (Gaydhane *et al.,* 2018).

3.2.2 Cell culture and its conditions

The next step in the process after extracting muscle cells from a live animal source is developing a cell line. Here cells are cultured in a culture medium with necessary in-vivo environmental conditions. Cell culture medium provides the nutrition and environment with an organism needs to grow. It supports and promotes the culturing of cells. Muscle cell culture (anchor-dependant cell, for example, myoblast) needs growth conditions such as (Zhang *et al.,* 2020; Stephens *et al.,* 2020) solid surface for attachment of cells (attached to suspended microcarriers) in order to consume food materials. The culture medium needs to be a replica of the *in-vivo* environment for the cultured meat so that it can be comparable to native meat. Culture medium should contain all essential micronutrients, amino acids and macromolecules such as lipids, proteins, carbohydrates and growth factors or hormones that are required for cell growth, viability and proliferation (*co-cultured hepatocytes can produce insulin-like GF that promote myoblast proliferation and differentiation). It is better to use plant-based or synthetic materials, without any animal-derived component, as it works towards eliminating animal dependencies.

Culture media used for a myoblast is usually animal sera commonly taken from an adult, newborn or fetal source. Fetal bovine serum (FBS) is the standard supplement for cell culture media. Chicken embryo extract is also used as an addition to some cultures. The serum contains a wide range of growth factors, hormones, vitamins, amino acids, fatty acids, trace elements and extracellular vesicles required for the promotion of cell growth but also brings the risk of contamination with viruses or prions. Also, the use of serum may raise some ethical concerns, so the use of serum-free media is preferred. In the last few decades, there have been studies utilising serum-free media for culturing mammalian cells. A serum-free medium usually consists of basal medium and medium supplements. The basal medium generally comprises amino acids, vitamins, glucose, and inorganic salts, which are essential factors in cell growth and metabolism. Chemical components or growth factors could be added to the serum-free medium as supplements. However, serum-free media shows poor growth performance as compared to serum media. More time and research are required to make a synthetic serum -free media since these chemically defined media are built using computer-aided design and synthetic biology and it is a challenge to identify and substitute all the functional components in sera into the serum-free media.

3.2.3 Scaffolding

A scaffold is required with appropriate characteristics to allow cell adhesion and subsequent proliferation and tissue development. It is used as a carrier of embryonic myoblasts (attachment-dependent) or satellite cells derived from animals through biopsy. For cultured meat, a scaffold and its by-products must be edible and may be derived from non-animal sources. Generally, collagen-based meshwork or micro carrier beads for suspended cultures are used as a scaffold since they are biocompatible and biodegradable. The cells cultured on scaffolds are introduced into a stationary or rotating nutrient-filled bioreactor. The design of the bioreactor should stimulate the growth of tissue with adequate oxygen perfusion. Rotating wall vessel bioreactor rotates in such a way that its speed balances the centrifugal force, drag force and gravitational force and allows the three-dimensional culture to submerge in the medium which helps in developing the structure of tissue similar to that of in vivo. Another type of bioreactor is the direct perfusion bioreactor. They are more suitable for scaffold-based cultivation. Here, the medium flows through a porous scaffold with gas exchange occurring in an external fluid loop. The cells get fused to form myotubes which differentiate into myofibers with the help of differentiation media. This technique produces soft consistency meat or boneless meat (Gaydhane *et al*., 2018; Stephens *et al*., 2020).

3.2.4 Scale-up production (Bioprocessing)

Tissue engineering on a very large scale is the second requirement along with the maintenance of constant conditions around all individual cells in a large-scale reactor with sophisticated instrumentation for measuring and controlling conditions. The need for cell growth and differentiation and subsequent release from support without damage upon harvesting is the third requirement along with the need for on-site cleaning and sterilization systems in large-scale reactors. The bioprocess can be considered into four parts: cell expansion; cell differentiation; product manufacture; and waste optimisation. Apart from that, raw materials and waste products, plus logistics, factory siting, and other associated infrastructure, and the associated Life Cycle Assessment are essential parts to understand the carbon

https://doi.org/10.26656/fr.2017.7(2).772

footprint of the process. Large-scale production is yet to be studied and developed due to difficulties associated with reactors and the process of scaling up cultured meat. For cultured meat as a bulk commodity to compete effectively with conventional meat, the reactor and process need to be up-scaled by two orders of magnitude, for which serious engineering challenges need to be addressed. It is important to examine these challenges w.r.t the type of reactors that can be used for large-scale cultured meat production (Gaydhane *et al.,* 2018; Stephens *et al.,* 2020).

3.3 Alternate methods for the production of artificial meat

3.3.1 Organ printing

It involves the spraying of live cells or balls of cells in layers over the gel that acts as a printing paper. Later, the cells get fused to create the 3D structure of any shape. Mostly, stem cells from a proper source such as a cow's umbilical cord are proliferated in bioreactors wherein the muscle and fat cells are separated. The cells are then mixed in a collagen-based hydrogel or any other compatible bioink (mimics the ECM) in order to support cell adhesion, proliferation, and differentiation. The tissues are then allowed to crosslink via photo, thermal or chemical crosslinking. The bioinks are then finally loaded into the print nozzle of bioprinter that prints the tissue layer by layer. Finally, the tissue is placed in a growth medium to grow and mature (Kang *et al.,* 2021). This is an advanced technique, that has the capability of producing an entire organ and can take care of meat consistency, vascularization, fat marbling and other elements of conventional meat-like taste and appearance. Finding these factors an expert in tissue engineering and biomedicine, now the founder of the Barcelona-based startup Novameat develops the technology for 3D printing a plant-based steak first created a prototype of the human ear and later patented the method for creating meat substitute using 3D printers (Carlota, 2019). However, this technique is expensive and underdeveloped (Gaydhane *et al.,* 2018).

3.3.2 Nanotechnology

Nanotechnologists are working on creating nanorobots or assemblers which can selectively group similar atoms or molecules forming the entire structure. It can virtually create any substance of any desired shape in a primitive state (Gaydhane *et al*., 2018). Meat tissue can be produced by self-replicating Nano-devices using small changes in material, energy, low capacity, labour and land, making the production more efficient. Here, meat is naturally composed of nanofibers that undergo changes during cooking or processing, which in turn influence the texture and eating quality. In order to match public expectations and achieve their acceptance, manufacturers need to deliver an alternative that gives the taste and texture of meat, which is possible to control at nano-level since many of the molecular structures that determine these characteristics are in the nanometer range (Rajkumar *et al.*, 2006).

4. Commercialization of cultured meat and other challenges faced

4.1 Commercialization

The world's first cultured meat (beef burger) was produced by a Dutch scientist Professor Mark Post of Maastricht University with financial support from Google co-founder Sergey Brin which was cooked and eaten at a London press conference in August 2013. This invention cost over £200,000 to make but also triggered great interest from media and investors that led to a dramatic rise in the number of CM companies, especially within the past 2 years like Memphis Meats, Eat Just and Finless Foods which are working to create lab-based alternatives to beef, chicken, pork and other animal products. These start-ups have received considerable interest and investment from major players in the tech industry. In 2019, Future Meat Technologies successfully raised $14m for the construction of its manufacturing facilities, while Memphis Meat has scooped $180m in funding to date. Start-ups in this area have also attracted investment from the likes of Bill Gates and Richard Branson. As of now, there are over 100 companies worldwide working on cultured meat in one way or another. Many of the new companies are already focused on supporting the growing industry and not on the core of meat production, such as lowering the cost of the cell feed or improving fermentation design to optimise efficiency, showing the maturity of the industry and the proximity to commercialisation and market entry. With the global population expected to reach 9 billion by 2050, researchers are looking for alternative means of food production that can produce food on a large and sustainable scale. Over the next few years, the major changes in the global meat market will be driven by the development and industrialisation of biotechnological processes. The research firm predicts that by 2040, 60% of meat products eaten will either be lab-grown or replaced by plant-based meat alternatives. ResearchAndMarkets reports show that the global cultured meat market is to be worth $291.4 m by 2027 with improved scientific methods and consumer acceptance (Daniel, 2021).

4.2 Bioprocessing and cost

However, the path to the commercialisation of cultured meat faces a few hurdles that need to be

https://doi.org/10.26656/fr.2017.7(2).772

overcome. Bringing cultured meat to market at a scale and cost comparable to conventional meat in the future years when meat demand is going to double, will be difficult. So far cultured meat production has been on a small scale where products are available in just a few restaurants. To achieve commercialisation, and get products onto supermarket shelves, production and supply chains must be ramped up considerably. Commercialisation requires the deployment of largescale bioreactors. A 5,000-litre bioreactor is needed to produce just 1kg of protein from muscle cells. Commercially available production-scale bioreactors for cell cultures are typically 1–2 m^3 in working volume. There are many reasons that smaller reactors might be preferred for cell culturing, e.g., multiple smaller units offer greater flexibility to adapt a plant's throughput and product portfolio to market fluctuations, they also offer easier damage control in case of contamination. This is not only crucial to competing with the traditional meat industry in terms of scale, but also in terms of cost. According to the Adam Smith Institute, the cost of producing a lab-grown burger fell from £250,000 to around £8 between 2013 and 2018. However, this remains high when compared with traditional meat production. For instance, a prototype lab-grown chicken nugget produced by San Francisco start-up Eat JUST costs $50 to produce. In comparison, A McDonald’s chicken nugget costs less than $0.10 per unit (Zhang *et al.,* 2020; Daniel, 2021).

4.3 Avoiding the use of animal-derived products

The objective of this invention is to prevent animal slaughter and reduce human dependency on animals and animal-derived products. However, for production of cultured meat, during the development of muscle cell lines, it is very important for the culture cells to grow adequately with a sufficient amount of nutrition and proper in vivo like environmental conditions. This is provided effectively by serum however, the serum-based medium FBS (fetal bovine serum) is made from fetal calf blood serum. Even though it is difficult to grow animal cells in serum-free media, it is possible today with the use of serum replacements. Ultroser G is one of many commercially available serum substitutes designed to replace fetal bovine serum for the growth of anchorage-dependent cells as it contains all the necessary constituents for eukaryotic cell growth (Stephens *et al.,* 2020). Albeit, to replace the serum media completely, all components of the blood serum have to be identified and duplicated synthetically using CAD, machine learning and AI. Research is in progress however more time and resources are required. Muscle cell culture media are expensive and limiting on the large scale, therefore, the manufacture of sustainable, animal-free, affordable media is a major challenge.

4.4 Contamination

The integrated, closed systems with increasing automation of large-scale bioreactors reduce errors and contamination risks associated with human handling. The frequency of contamination of cells and harvests by viruses is low for products of biotechnology. As with components of cell culture media and scaffolds, documented controls and assays, such as polymerase chain reaction (PCR) and chromatin immunoprecipitation (ChIP) assays, can be used to detect abnormal levels of substances and ensure such deviations are brought back to suitable levels. The substances used during production and the final composition of the cell-cultured meat product are important in determining safety. For instance, a cell-cultured meat product composed of a mixture of cell-cultured meat and other ingredients such as binding, flavouring ingredients, and plant-based materials used in conventional food products, will need to be evaluated for safety for each ingredient (Murraille, 2019). The Federal Food, Drug, and Cosmetic Act (FD&C Act) Section 402 consider food adulterated if it bears or contains any food additive that is unsafe within the meaning of section 409 of the Act. Food is also considered adulterated if it has been prepared, packed or held under insanitary conditions whereby it may have become contaminated with filth, or whereby it may have been rendered injurious to health. Apart from that clean cultured meat is produced by biological manufacturing techniques where cells and tissues are grown in sterile environments and carefully monitored for contaminants. As the process only grows muscle, it would not be associated with gut bacteria, thus faecal contamination would not be possible during the production process. Antibiotics are typically used in meat animals and poultry to fight disease and speed the animals’ growth; however, the lab meat researchers use antibiotics in cultured meat is not required because the sterile laboratory process makes them unnecessary. This has important implications for human health as well, especially when it comes to concerns about antibiotic-resistant drugs. According to the Centre for Food Safety, 70% of medically important antibiotics and 80% of all antibiotics sold in the U.S. each year are marketed to food animal producers.

4.5 Regulations

Under a joint agreement accounted for in March 2019 (USDA and FDA, 2019), the U.S. FDA and the U.S. Department of Agriculture’s (USDA) Food Safety and Inspection Service (FSIS) agreed to jointly oversee human food products incorporating cultured cells from livestock and poultry. FDA is responsible for overseeing cell collecting and cell culturing and conducting premarket consultations on production processes. FSIS oversees the processing, packaging, and labelling of harvested cellular material. FDA and FSIS share oversight of the harvesting of live cellular material. Both the FDA and USDA–FSIS will inspect cell-based meat and production facilities, but USDA–FSIS will be solely responsible for inspecting the final stages of production. The formal agreement states that cell-based meat must bear the USDA mark of inspection and the FSIS must pre-approve all labels on slaughter-based meat packaging. The Federal Food, Drug, and Cosmetic Act (FDCA) grant the FDA the authority to regulate food production in the United States to ensure that all domestic and imported food products — except for most meats and poultry — are safe, nutritious, wholesome and accurately labelled (Estrada, 2020).

Contrary to the United States, the regulatory framework for cultured meat in the EU has been in place since 1997 and was updated in 2018. Depending on the starting cell types used, either the EU Novel Foods Regulation or the genetically modified organism (GMO) legislation (embodied by the GMO Directive and GMO Regulation) will be applicable. The EU Novel Food Regulation excludes genetically modified foods and therefore the use of iPSCs for cultured meat production will most likely be covered by the EU GMO legislation. Under the EU Novel Foods Regulation, an application for authorization of cultured meat should be made via the e-submission system operated by the European Commission, which will subsequently distribute the application to all EU member states. Minimum requirements for the application consist of information on the identity of the product, its production process, compositional data and specifications, proposed uses, use level and anticipated intake of the product. Other safety information relates to the source of the product; absorption, distribution, metabolism and excretion (ADME); nutritional and toxicological information; and allergenicity. Applications are evaluated on a case-by-case basis. On receipt of the novel food application, the European Commission will usually request a safety opinion from the European Food Standards Authority (EFSA), which will evaluate if the novel food is of comparable safety to food from a similar category already on the EU market (Stephens *et al.,* 2020).

A key concern of the regulations will be safety. This requires an awareness of auditing that should be addressed from the outset of animal cell-based cellular agriculture product development as it brings together cell culture and meat science. In terms of processing, auditing should include (i) identification of key possible pathogens, and safety measures to inhibit contamination (through a HACCP-based system), (ii) ensuring ageing of meat is greater than 24h to allow for total cell death, (iii) monitoring and quality assurance of cellular functions at each stage (viability, self-renewal, death and differentiation) are pivotal to quality, function and sustainability, assays for cell potency, and testing of genetic stability, (iv) the managing of metabolic waste by disposal, recycling or upgrading, and (v) production plant hazard and operability study (HAZOP) (Stephens *et al.,* 2020).

4.6 Public acceptance

All the other challenges can be overcome via some strategy or technology. However, consumer opinion and acceptance are challenges that cannot be tackled with any strategy or technology. Albeit the fact that cultured meat has more pros to its cons, it diminishes animal dependency and is environmentally sustainable, the fact it is something man-made, and an unnatural laboratory product that makes it difficult for people to accept it. People have the belief that anything which is natural is healthy and safe compared to synthetic material. Many people seem to want the meat to come from animals that have lived as naturally as possible, but they are concerned about the way many meat-producing animals are raised and killed. However, the naturalness of the product is not a major concern for many people, other challenges include safety and health concerns, and consumers are not sure that cultured meat is safe and wholesome in the long term. Disgust sensitivity and neophobia — an aversion to new or unfamiliar foods — increase the rejection of cultured meat. Apart from the population that rejects the product, there has been a good percentage of acceptance of the product as well. Researchers found that a high proportion of consumers would try to buy or eat cultured meat, and they tended to perceive it as more beneficial to society than to themselves. Cultured meat seems to be more accepted than genetically modified foods, more appealing than eating insects, but less accepted than plant-based meat, it is most appealing to people who love meat. In addition, studies showed differences in the acceptance of cultured meat between countries. For example, Chinese and Indian consumers were more positive about it than those in the United States. Young people found cultured meat more appealing than older people; the same was true for urban dwellers as well as for meat eaters compared to vegetarians. Moreover, men were more likely to accept cultured meat than women, more educated people were more likely than less-educated people, and liberal people were more likely compared to conservative people. The study found that consumers consider avoiding animal suffering as one of the main benefits of cultured meat. They also believe that cultured meat has environmental benefits, such as reduced greenhouse gas emissions and reduced water and land use. In addition, they can see it

https://doi.org/10.26656/fr.2017.7(2).772

as a potential solution to resolve global hunger and global warming. Price and taste are two crucial aspects for consumers, and they were found to be important factors in purchase intentions. Some people were willing to pay more for cultured meat than traditional meat, but not everyone. For the latter, cultured meat will have to be affordable, and in addition, it needs to be tasty. At the moment, consumers think that cultured meat will not taste as good as traditional meat. Several strategies can be implemented to increase the acceptance of cultured meat. The researchers highlighted that presenting positive information about the benefits of cultured meat seems to increase its acceptance. Details about the personal benefits to the consumer would be among the most effective types of information. In general, it may be beneficial to avoid overly technical explanations. The name is also important. Clean meat seems to be the name that leads to the highest acceptance (Bryant and Barnett, 2020).

5. Conclusion

In vitro meat holds great potential to replace slaughtered animal meat and meat-based products. The growing global demand for meat is a considerable challenge, owing to increasingly serious resource and environmental constraints. Although cultured meat is considered a promising alternative to conventional meat, it is still in its early stages and lacks a solid foundation: artificial meat lacks the necessary nutrients, it is costly, and food safety certification has not yet embraced it. Moreover, there are fundamental issues that need to be resolved, pertaining to social and ethical constraints, efficient tissue engineering, fine-tuned culture conditions, large-scale bioreactors, and the development of cost-effective and safe serum-free culture media. Based on existing research, there are some main risk factors for cultured meat, such as food safety certification of components used in cultured meat, and genetic engineering applied in cultured meat. In general, however, with increasing demand and further development of biotechnologies, cultured meat may ultimately compete with conventional meat as a slaughter-free and sustainable choice, with the potential to relieve the stress from an increasing population and demand for meat. Many start-ups have been established in the past 10 years that are working towards a feasible solution to this. Memphis meat- hopes to scale in such a way that less land, water, energy, and food inputs are consumed by the meat industry, and quality, healthy, and safe cell-based meats can reach grocery stores in the coming years. Finless Foods are creating sustainable, cell -based seafood products, starting with bluefin tuna. This achievement would help solve the environmental problem that commercial fishing is causing and would improve the nutritional quality of the fish being consumed. Meatable is creating hamburgers from single animal cells, in a much faster, cleaner, and more sustainable way than traditional livestock-sourced burgers. Their process claims to produce a hamburger in 3 weeks or less, which, when compared to the minimum 3 years traditional meat takes, is a significant improvement. SuperMeat is working to create animal-friendly meat products in partnership with PHW-Gruppe, one of Europe’s largest poultry producers. Like all the other companies here, their product will help solve the environmental impact issues of the meat industry, but SuperMeat’s marketing and branding also focus on the humanity of how this type of meat production will prevent the slaughter of animals. Mosa Meat was the ground-breaking company responsible for the first lab-grown hamburger showcased in 2013. Since then, they’ve been hard at work to get their products ready for commercial production, and are aiming to make them available to consumers within the next few years. Their main goal is to bring cultured meat (or “clean meat” as they call it) to the mass market to help satisfy the growing demand for meat, which they believe will hit a critical stage by 2050. They also claim that while the process is very expensive now, over time, they will be able to reduce the price to about the same as a typical beef hamburger in the supermarket (Mah, 2019).

All these and many more start-up companies are working towards a sustainable solution to issues like animal slaughter, world population and environmental destruction, cultured meat poses a great opportunity for humans to change their lifestyle into a much healthier, long-lasting and animal-independent lifestyle. I have personally tried to abstain from meat for 3 months while writing this review, at first it seemed difficult for me as I am a meat lover, but with the right kind of motivation, I was able to quit it for over 8 weeks. For me, it wasn’t that difficult, since the majority of Indians are vegetarians. Thus, it is high time that the public as individuals quit relying on the government and environmentalists to do what needs to be done for fixing the environment, it is every citizen’s duty as an individual to do their own part as well. Shifting the lifestyle towards environmental sustenance and adopting a more organic and animal-free diet on an individual scale can do wonders to help the environment on a larger scale.

Conflicts of interest

The authors declare no conflicts of interest.

https://doi.org/10.26656/fr.2017.7(2).772

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