Techniques, Challenges and Future Prospects for Cell-based Meat

Rituja Upadhyay (✉ rituja@karunya.edu)
Karunya Institute of Technology and Sciences  https://orcid.org/0000-0002-4428-5955

Anmariya Benny
Karunya Institute of technology and Science: Karunya Institute of Technology and Sciences

Kathiresan Pandi
Jahanom Private Limited, Coimbatore

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Abstract

The food industry has come up with a wide range of innovations, changes, and possibilities to create meat through in vitro conditions as a result of a proportionally expanding population and food demands. This breakthrough has the potential to completely transform the meat business, with far-reaching repercussions for the environment, human health, and animal welfare. Thus, animal cells rather than slain animals are used to make cell-based meat, where the proliferation and differentiation of the cells take place in the culture media. The main purpose of this paper is to analyze the overall mechanism and various techniques involved in cell-based meat production. It also discusses upcoming challenges such as technical, consumer, regulatory aspects, environmental issues, product costs, the economy, health safety concerns, ethical, religious, and social taboos. Finally, it analyzes the prospects of the cell-based meat production technique.

Introduction

Feeding 10 billion people by 2050 is humanity's top problem today (UNPD, 2019). Meat is one of the most significant dietary resources and nutrients for the vast majority of people, consuming over 300 million tons in 2014, with a forecast 76% increase by 2050 (Alexandratos et al., 2012). Each year, over 70 billion animals are raised and slaughtered throughout the world to meet rising meat demand (Dopelt et al., 2019). Large-scale animal raising and killing raises severe environmental, ethical, and health concerns. The major cons of conventional meat production are emissions of greenhouse gases from enteric fermentation and manure. Animal butchering pollutes the environment since it is unsanitary and violent. Crossbreeding to generate solely high-yielding animals has resulted in cattle loss of genetic diversity. The proliferation of weeds by animals has resulted in the loss of crops and natural wildlife variety, Soil erosion is caused by the grazing of meat-producing animals. Consumption of red meat raises ethical concerns and human health issues, Superbugs, and antibiotic resistance genes are spreading, as the drugs are leftover from animal feed. Farm animals provide a risk of zoonotic illnesses (viruses, bacteria, fungus, and other pathogens). Traditional livestock production has become increasingly uncertain due to epidemics of African swine fever, avian flu, and other animal illnesses (Dixon et al., 2020; Normile, 2008; Singh et al., 2020; Taylor et al., 2020). In light of these considerations, it is imperative to consider an alternative meat production technique that is highly efficient, ecologically friendly, and long-lasting. Cell-based meat has been hailed as one of the World Economic Forum's "Top 10 Emerging Technologies of 2018," and has been recognized as a plausible solution to problems in animal production (Cann, 2016; Jiang et al., 2020; Lee et al., 2020). Cell-based meat (also known as in vitro meat, lab-grown meat, clean meat, or synthetic meat) is edible muscle tissue created by culturing stem cells in a controlled culture and physiological environment in a laboratory utilizing tissue engineering and computational simulation technologies (Mengistie, 2020). In other words, cell-based meat is produced by growing stem cells outside the animal for human consumption from which it originates. For most cases, stem cells with the ability to self-renew and differentiate are isolated from an animal biopsy, and placing them into an appropriate medium containing nutrients, energy sources, growth hormones, and other variables needed for the stem
cells to develop and differentiate into adult muscle cells in a bioreactor, to create muscle fibers, fat, and other cell types that make up muscle tissue. Cell (or tissue) culturing may be used to produce edible animal muscle, often known as meat, which necessitates the multiplication of a small number of muscle cells into a big mass of tissue. After food processing such as shaping, dyeing, and seasoning, these cells are gathered and combined to produce edible meat end-products (Arshad et al., 2017; Bhat et al., 2015; Datar & Betti, 2010; Kadim et al., 2015). In vitro meat is envisioned as a viable replacement to traditional meat due to significant benefits such as animal-free production, up to a 50% decrease in energy use, 75–95% lower greenhouse gas emissions, 99% less land use, and 80–95% less water usage (Tuomisto & Teixeira de Mattos, 2011). Furthermore, as compared to actual animal meat, cell-based meat would have a far lower carbon impact. In contrast to conventional animal meat, where 75–95% of the feed ingested by the animal is used for metabolism and the formation of unpalatable body parts such as exoskeleton (hair, horns, and hooves) and neural structures, the energy needs will be decreased (Bhat & Fayaz, 2011). In the traditional system, various drugs, such as tranquilizers, additives, and steroids, are administered to the animals before they are killed to increase output and profit. Oftentimes, the animal’s body is not properly cleaned, and the animal becomes ill. All of these issues are avoided with lab meat. As cell-based meat is not produced from animals raised in enclosed spots, the risk of disease breakout is reduced. As a result, there is no need to produce expensive vaccines against deadly illnesses (Srutee, R.S. & Uday, 2021). Cell-based meat will become less expensive to produce in the long run, and it may be more cost-effective than regular meat if it is produced more effectively (Bryant, 2020). Thus, the outnumbered benefits of cell-based meat techniques compared to traditional meat production opened the field of scope for this innovative technique.

Cell-based meat is presently in its infancy because of its immature manufacturing method and high production cost, so researchers are eagerly working on technical improvements to speed up the industrialization and commercialization process (Guan et al., 2021).

**Methodology Used For Review**

The authors have tried to present an overview of existing cell-based meat production processes and analyze the technological hurdles for cell-based meat. Meanwhile, further research is being focused on the marketing and commercialization of cell-based meat (Figure 1).

First, Scopus and Google Scholar were used to perform a literature search. Data was gathered and discussed with appropriate references. Although the majority of the articles were published during the last decade, earlier references were included in some cases to emphasize conclusions and facts that had not before been reported in a comparable context. Recent advancements have been given more attention.

Figure1 Caption: Overview of the paper, detailing production techniques, upcoming challenges, and the prospects of cell-based meat.
Mechanism of production

The cell-based meat production method is a combination of tissue and food engineering techniques where the production process can be divided into four major steps as shown in figure 2.

Stem cell collection

Stem cells are a type of progenitor cell that may multiply and differentiate to develop specific functions (Dodson et al., 2015). Stem cells might be derived from muscle stem cells, or myosatellite stem cells (Fig2. Number A), induced pluripotent stem cells (Fig2. Number B), embryonic stem cells (Fig2. Number C). Muscle cells are usually obtained from embryonic stem cells (ES cells), microsatellite cells, or specialized cells in muscle tissue (Pandurangan & Kim, 2015). In general, these cells may be collected easily from a biopsy of living animal tissue following isolation by enzymatic digestion and mechanical disruption, as well as purification using flow sorting with particular surface markers (Ding et al., 2017). Although ES cell lines have infinite regeneration potential, mutations can accumulate over generations, and muscle cells require specialized stimulation. Myosatellite cells are restricted in their ability to regenerate, but they can better imitate myogenesis. These satellite cells develop quickly into myotubes and mature myofibrils, making them the best cell source for skeletal muscle tissue creation (Bach et al., 2003). Indeed, breakthroughs in cell culture techniques and stem cell engineering, particularly the formation of induced pluripotent stem cells (iPSCs) via genome reprogramming of somatic cells, are fueling research in the field of in vitro meat production (Singh et al., 2020). Although many cell sources can be utilized to make cell-based meat, each cell type requires a particular ex vivo expansion and differentiation method based on its growth and development characteristics (Fish et al., 2020; Stephens et al., 2018; Zhang et al., 2020).

Proliferation of cell

To reach enormous cell counts, stem cells must be multiplied once they have been harvested. The laboratory culture scale of flasks or dishes is insufficient to meet market demand, thus a large-scale bioreactor system (Fig2. Number D) is required (Post et al., 2020). A bioreactor should be designed in such a way that it promotes tissue development. Adequate oxygen perfusion during cell seeding and growth on the scaffold is critical to the success of scaled-up cell-based meat production. Bioreactors improve mass transfer between the culture medium and the cells, allowing for adequate oxygen perfusion. A rotating wall vessel is a type of bioreactor that revolves at a speed that balances centrifugal force, drag force, and gravitational force, allowing the three-dimensional culture to be submerged in the medium and assisting in the development of tissue with a comparable structure to that found in vivo. This type of bioreactor allows for maximum mass transfer with the least amount of shear stress. Direct perfusion bioreactors are another form of the bioreactor, more suited for growing on scaffolds. Medium is circulated via a porous scaffold, with gas exchange taking place in an external fluid loop. This type of
bioreactor has a high mass transfer rate and a lot of shear stress (Kurt et al., 2021). A cell culture medium (Fig2. Number E) is used for stem cell growth and subsequent differentiation into muscle cells. Danoviz and Yablonka-Reuveni used three primary elements to successfully develop proliferation and differentiation of myosatellite cells: Dulbecco's modified medium (DMEM), Fetal bovine serum (20%), and horse serum (10%). According to the study, the DEME is a four-fold concentration of vitamins and amino acids that is a variation of Basal Medium Eagle (BME). It also has a high glucose concentration of 4.5 g/L, 0.11 g/L sodium pyruvate, 100 U/mL penicillin, 0.0000001 g/L streptomycin, and 0.004 M L-glutamine. Fetal bovine serum (20%) contains fibroblast and insulin-like growth factors, has no heat-activated properties and promotes myoblast differentiation and proliferation. Horse serum (10%) was chosen because of its capacity to promote myoblast differentiation and proliferation (Danoviz & Yablonka- Reuveni, 2012). After two weeks in culture, 81% of the cultures showed tissue adhesion to the culture vessel, 63% showed self-healing, and 74% of the cultures showed cell proliferation utilizing a self-organized technique. When employing fetal bovine serum as the nutritional medium, the explanted tissue expanded over 14%, and over 13% when using mushroom extract. The discovery of goldfish explant tissue development in serum-free media was groundbreaking. The most difficult challenge for cell-based meat is replacing the serum-free medium with natural extracts, which scientists and firms are still working on (Benjaminson et al., 2002). At the same time growth factors are required for cell proliferation and growth. Purified growth factors or hormones from plants, animals, or transgenic bacterial species can be added to the culture medium to produce recombinant proteins (Houdebine, 2009). Furthermore, the method should employ a cost-effective serum-free medium and online monitoring of different parameters such as pH, dissolved O\textsubscript{2} and CO\textsubscript{2}, concentrations of key nutrients, and metabolic waste (Allan et al., 2019). At the same time, it is critical to undertake medium recycling with automated removal of hazardous wastes and replenishment of nutrients based on monitoring feedback to optimally utilize resources and maintain low production costs (Guan et al., 2021).

**Differentiation of cell**

Proliferated cells (Fig2. Number F) have to be seeded into the scaffolds, scaffolds (Fig2. Number G) are heterogeneous structures that impact characteristics such as texture when it comes to structuring differentiated muscle cells. As collagen-based meshwork and microcarrier beads are biocompatible and biodegradable, they are commonly used as scaffolds. The scaffold-cultured cells were plated in a nutrient-filled bioreactor, which can be either stationary or rotating. Myotubes (Fig2. Number H) are formed when cells combine with the assistance of differentiation media, develop into myofibers (Fig2. Number I). This method yields meat with a soft consistency or boneless meat, which may be used to make hamburgers and sausages, along with other things. The primary disadvantage of this method is that it cannot create highly structured or 3D structured meat, such as steaks. Myoblast and fibroblast co-culture is a promising method for in vitro meat production (Ding et al., 2017). Cells are stimulated to develop into myotubes, adipocytes, or other mature cell types in muscle tissues once the necessary number of cells has been reached. Because features, structure, and nutrient content, such as proteins,
fatty acids, and vitamins, are significantly impacted by cell maturity, the maturity degree of the produced final cells is a critical assessment criterion at this stage (Wuyi, 2019). Although muscle stem cells are thought to have a high potential for myogenic differentiation, the diameter, length, and protein content of ex vivo generated myofibers vary considerably depending on the culture conditions and may be substantially lower than actual muscle fibers (Braga et al., 2017; Lamarche et al., 2021; Park et al., 2016). As a result, based on the process of in vivo muscle tissue growth, it is critical to optimize the differentiation state and improve the maturity of differentiated cells (Wuyi, 2019).

**Cell harvest, assembly, and food processing**

The acquired mature cells are collected and processed, including molding, coloring, and seasoning, as the final stage in the cell-based meat manufacturing process, resulting in the cell-based meat end-product (XinRui et al., 2019). As traditional cell culture can only produce a two-dimensional (2D) thin cell layer, the assembly of myofibers, adipocytes, and perhaps connective tissue cells are required to produce a piece of marbleized and structured meat (Zhang et al., 2020). Furthermore, the molding technique may be included in the stage of cell differentiation, in which different cell types are co-cultured in a biomimetic three-dimensional (3D) environment supplied by the scaffold or hydrogel (Tuomisto & Teixeira de Mattos, 2011). Finally, food processing such as heme protein addition and flavoring substances might result in the final product (Wuyi, 2019). Through various food processing techniques, cell-based meat can be used to produce various edible products like burgers, sausages, and so on (Fig2. Number J).

Figure2 Caption: Stem cell technique for producing cell-based meat.

**Production techniques**

The techniques used for the production of cell-based meats are grouped as conventional and prospective approaches.

**Conventional techniques**

Self-organizing and scaffolding approaches are the two techniques under the conventional method of cell-based meat production. The self-organizing approach utilizes muscle tissue for in vitro culturing, whereas in the scaffolding technique, stem cells are used for proliferation and differentiation into myofibrils.

**Self-organizing/Tissue culture techniques**

Cell-based meat was created by separating muscle stem cells and assembling them in a structured way. Coculturing the cells in a suitable medium also allows for the proliferation of existing muscular tissue.
Cell-based meat was first produced by this technique when it was performed on fish muscle development from explants of Carassius auratus (goldfish) by Benjaminson and colleagues (2002). They cultured the skeletal muscle explant in a diverse medium for seven days and observed that the explant with dissociated goldfish skeletal muscle showed high growth and looked similar to that of a fresh fish filet due to culture media, which mimics to in vivo condition. It also addresses the testing of a range of growth mediums, including fetal bovine serum, fish meal extract, and mushroom extracts. Also examined how each growth medium improved the explant’s muscle tissue growth, prompting him to look for alternatives to fetal bovine serum (Benjaminson et al., 2002). As the explant contains all the tissues, this technique can get highly structured meat similar to that of in vivo meat without the use of scaffolds. The main drawback of this technique is the necrotic of the developed cells due to the absence of blood supply, nutrient supply, and detachment of cells from the surface. This is because only in certain conditions culture media can mimic in vitro meat. Coupling of tissue culture with tissue engineering can overcome this drawback by culturing the tissue explant onto the network of edible porous polymer scaffolds through which nutrients can be perfused to the cells by acting as an artificial capillary (Zandonalla, 2003). Furthermore, bioreactors with low shear force and uniform perfusion for large volumes have been designed as customized bioreactors.

**Cell culture/scaffold-based technique**

This approach is the second type of cell-based meat production technique, where highly structured meat-like streaks cannot be produced but soft consistency or boneless meat can be produced because of the use of scaffolds. Scaffolds, as being a porous biomaterial, have an inevitable role in tissue engineering by providing temporary structural support, aiding in the transfer of vital nutrients, removing waste materials, and promoting the development of functional tissues as well as organs. From a piece of muscle tissue from differentiated myotubes, that can be multiplied to more than a trillion strands by placing them in a ring on a scaffold which allows them to increase their size and protein content (Bhat et al., 2017; Chriki & Hocquette, 2020; Mengistie, 2020). In this technique, stem cells, viz., satellite cells, ESCs, and iPSCs are isolated and cultured and/or co-cultured with adipocytes. Thus, the differentiation from myotubes to myofibers takes place when stem cells are embedded in edible scaffolds or carriers such as collagen meshwork or microcarrier beads. Finally, the obtained myofibers can be collected, processed, cooked, and eaten as an emulsion or as a ground meat product (Bhat et al., 2015; Drury &Mooney, 2003). Even though differentiation of myotubes from stem cells and myofibers from myotubes are the most critical steps, this can be accomplished by creating developmental pathways of muscle fibers in vitro. For that, various growth factors and signaling molecules like insulin growth factor (IGF), platelet-derived growth factor (PDGF), basic fibroblast growth factor (bFGF), hepatocyte growth factor (HGF), Wnt3a, Wnt7a, Notch, and forskolin are used (Chargé & Rudnicki, 2004; Will et al., 2015).

One of the major concerns is the difficulty of building adequate scaffolds with the right thickness and mechanical qualities to allow cell adhesion and growth. The biomaterials used to make scaffolds must be edible and/or biodegradable, while also maintaining their structural integrity and supporting cells in
bioreactors. To recreate the feel of traditional meat, the scaffolds must allow for the proper arrangement of lipids, muscles, and connective structures (Choudhury et al., 2020).

**Prospective techniques**

With recent advancements in technologies and scientific innovations in the field of cell-based meat, various emerging techniques like organ printing, nanotechnology and biophotonics fall under the prospective approaches for cell-based meat production.

**Organ printing**

For small-scale production of cell-based meat, cell culture and tissue culture can be utilized but they lack the fundamental features and aspects of usable and appropriately tasting meat, such as vascularization, consistency, and fat marbling. Other hypothetical alternatives, such as organ printing, could, in the future, provide a viable option for producing fully structured flesh. Three-dimensional (3D) or four-dimensional (4D) bioprinting technologies can be used to manufacture biological tissue constructs that replicate the anatomical, structural, and functional characteristics of original organs or tissues when used in conjunction with tissue engineering concepts. Organs manufactured using 3D printing technology would not only resemble the fundamental cellularity of the individual organ but would also have adequate vascularization to provide blood flow to the complete product (Bhat et al., 2017; Gillispie et al., 2019). 3D printing is a recent, advanced, and sophisticated tissue engineering technique, where the required 3D shape and structure can be obtained by fusing sprayed cell encapsulated hydrogels over a printed scaffold (Jung et al., 2016). 3D bioprinting is one of the most powerful and appealing tools for providing functionally and anatomically similar organs or tissues for regenerative tissue and organ clinical applications because it deposits biomaterials and multiple cell types into a single 3D tissue architecture with high precision. 4D printing is an extension of 3D printing that adds one more dimension of transformation over time where the target organs or tissues are sensitive to parameters like humidity and temperature, and this technology is used for tissue regeneration such as muscle, bone, and cardiovascular tissues, and it uses similar technology (Javaid & Haleem, 2019). There are a variety of 3D printers available, including laser-assisted, inkjet, and microextrusion bioprinters, with different printing precision and specifications.

Microextrusion printers are slower and less expensive and work with the continuous release of materials. Laser-assisted printers are the most expensive, with the highest resolution. Ink-jet printers are the least expensive, with small droplet sizes and a viscosity (Bhat et al., 2019). The sole disadvantage of this method is that it is costly and still under development (Gaydhane et al., 2018). Spraying a suspension of myoblast cell encapsulated hydrogel over a gel generated from biological sources might lower the cost of in vitro meat production (Singh et al., 2020). Researchers from all around the world have sought to create tissue-like biological constructions using various hydrogel compositions and cell kinds. Organ printing is still in its infancy, and existing bioprinting options face greater technical challenges in terms of controlled
cell distributions, high-resolution cell deposition, innervation, and vascularization within complex 3D tissues, despite its potential in regenerative medicine to generate several transplantable tissues, including cartilage, skin, and bone (Mandrycky et al., 2016). Due to the presence of vasculature and intramuscular fat, cell-based meat mimics of specific components such as beef steak, pig shoulders, and other meats often require spatial resolution and redefinition, which will affect the taste, flavor, and texture to resemble the originals. This can be addressed using 3D Printing by upgrading scaffolds (ideally hydrogel scaffolds), introducing diverse muscle types, and even generating functional organs in ex vivo (Lee et al., 2019). The 3D printing of muscle is characterized by cell distribution, alignment, and synchronization during contraction; nonetheless, biochemical compatibility, resolution, and throughput are key concerns (Beauchamp et al., 2017). According to a recent study, the mechanical properties of meat-ink are also a determining factor of 3D-printable meat products. In the case of mouse myoblast cell culture (C2C12), the choice of bioprinter nozzle, pressure, and shear stress influence cell development and differentiation (Handral et al., 2020). Overall, the benefits of 3D printing include the speed of production, form modification, even distribution of nutritional content (protein, fat), and ease of handling, even in space stations. For the first time in 2021, an Israeli company called "Aleph farms" produced a 3D bioprinted ribeye steak (Liu et al., 2017; Newswire, 2021). Nonetheless, 3D printing may offer unique options for managing the nutrient profile of cultured tissues, particularly fat and proteins, as well as the critical challenges of cell-based meat production, such as protein, fat, and other nutritional content, as well as realistic texture (Handral et al., 2020). In the future, 3D printing can tailor 3D foods with selective nutrients and custom-made textures and shapes in the food industry. However, one of the most important aspects of 3D printed food's adoption is their distinctive appearance. Several studies indicate that these manufactured meals should be regarded as unique to boost entrepreneurship and growth in the future for a more sustainable food chain. Surprisingly, experts believe that the future perspective will be a culmination of 3D printing mixed with cooking on a single device, which is a fundamental potential for the development of 4D printing equipment to help with food supply and management (Baiano, 2020). In vitro meat combined with 3D printing technology provides an uncompromised answer for preventing future food crises, avoiding animal cruelty, and drastically reducing greenhouse gas emissions and water waste. Nutrigenomics can be used to create customized food based on a person's genetic information, lifestyle issues, and nutritional deficiencies (Prakash et al., 2019).

**Nanotechnology-based technique**

Nanotechnology is a fast-developing technology that involves the testing, manufacturing, and modification of nano-sized materials less than 100 nm in diameter that contain unique qualities (Tabassum et al., 2018). Nanotechnology is the creation and modification of materials at the atomic and molecular level. With an idea of a speculative technology in mind, such as some kind of an assembler, a robot with the size of a molecule that would allow moving matter at the atomic and molecular level, this rapidly developing science offers immense potential. With the aid of these molecular-scale small robots, nanotechnologists are investigating all of the potential and helpful technological interventions that they would want to make. Knowing that everything is made up of the same fundamental atoms that are just
organized in different ways allows us to build almost any material we desire from the ground up by putting together exactly the molecules we want (Bhat et al., 2017). As the nanofibers exist naturally in meat and impact the texture and color of meat after cooking, nanotechnology can play a key role in the development and packaging of innovative meat products. Furthermore, nanotechnology is commonly employed in the packaging of meat products. Beef products are packaged using a packaging film made of nanoclays distributed on a polyamide-6 (PA6) matrix. This nanoclays packaging film enhances the stiffness of meat products while increasing the O₂ barrier characteristics (Picouet et al., 2014).

Nanotechnology’s function in meat packaging has several benefits, including mechanical tolerance, heat resistance, increased biodegradability, and improved barrier qualities. They can also be used with antimicrobial boosters and spoilage detectors as packaging materials. While layer-by-layer (LbL) deposition techniques can be used to wrap meat and other food goods in nanolaminates or edible coatings, which can increase the shelf-life of the products. These cutting-edge packaging techniques ensure meat quality during transit, allowing for preservation and possible distribution, as well as a fluid communication pipeline with consumers (Sharma et al., 2017). In addition, higher nutritional bioavailability, improved sensory acceptability, targeted distribution of bioactive compounds, and increased antimicrobial effects of preservatives are also possible areas for nanoscience intervention in meat science and technology (Singh et al., 2020). Food-based nanosensors such as e-nose, e-tongue, and lab-on-chip nanosensors for pathogen detection, surface-enhanced Raman scattering-based sensors, and aptamer-based sensors are exclusively used to detect the presence of microbial pathogens, pollution, and poisons. They have the potential to provide benefits such as quick sensitivity, accuracy, and functional detection to help remove pollutants and provide quality meat to stakeholders (Kulshreshtha et al., 2017).

**Bio-photonics**

There are also additional speculative options for cell-based meat, such as biophotonics, a technique that employs light to hold matter particles together (Bhat et al., 2019). Biophotonics, a novel process of utilizing light to bind together particles of matter, is a new possible technology for the creation of in vitro meat that depends on the effects of lasers to move particles of matter into particular organizational structures. Although the processes of this field are yet unknown, it creates so-called "optical matter" in the form of three-dimensional chess boards or hexagonal arrays, in which crystalline materials, such as polystyrene beads, can be bound together by infrared light nets. When the light is turned off, the substance will disintegrate (Bhat et al., 2017). It can eliminate the need for scaffolding in tissue formation by keeping cells together with laser light (Gaydhane et al., 2018).

**Upcoming Challenges**

Various challenges affecting cell-based meat production are discussed below, and it is summarized in table 1.
The primary step of optimal cell source collection for cell-based meat production is a challenging one. Even though the initial sources of cells are from cell lines or primary cells, both have their drawbacks. Cell lines can be genetically created and chemically generated, or they can arise naturally through mutations (Ramboer et al., 2014). These immortalized cells accelerate proliferation and differentiation, potentially reducing the need for new animal biopsies. However, cell lines have some drawbacks, including sub-culturing, misidentification, and continuing evolution (Stephens et al., 2018). Another alternative is to collect the primary cells found in the original tissues, which would involve keeping a small herd of animals to harvest cells on a need basis for culture. The most commonly studied stem cells are those taken from muscles (satellite cells). However, mesenchymal stem cells and other multipotent cells are now being studied due to their ability to expand in the absence of animal serum and their higher proliferation capacity. Embryonic stem cells, which have an endless proliferation capacity, is also an option, although steering them toward a muscle cell lineage is more difficult (CookMyosite, 2016). Primary cells obtained from humans are also available for research. Harvesting the appropriate cell type from the original tissues, both in terms of cell counts and homogeneity, can be costly and technologically complex, and often the obtained cell number is insufficient for meaningful interpretation. Sample variability will also alter the responsiveness of cells to the culture environment and their growth behavior. Which animal species, breed, and tissue will result in the best cell supply is yet unknown and is a major issue (Bhat et al., 2019).

One of the key priorities for cell-based meat as a cell culture-based product is the creation of an appropriate culture medium. The culture medium, in particular, must not only support efficient cell proliferation and differentiation, but also take into account factors such as cost, availability, and food safety (Guan et al., 2021). Then, from plant-based and microorganisms, cultured media components are currently from animal origins, such as chicken embryo extract, fetal calf serum, or horse serum. All animal components should be eliminated from the cell-based meat manufacturing process to comply with the goal of cell-based meat, which is to avoid animal husbandry and slaughter. Including serum in the production system will not only cause acceptance concerns but will also result in a slew of other complications of similar severity. The massive supply of serum-based media required for commercial production would not be practicable or ethically feasible, aside from being a potential source of contamination and infections and a source of significant variance between batches, are the reasons. Furthermore, to ensure optimum safety, sustainability, controllability, and accuracy of the cell culture process, the creation of serum-free and animal component-free media is critical. It is conceivable and viable to construct serum-free mediums aimed at a single cell type, enabling precision nutrition supply during its proliferation and differentiation phase. However, no such media exists for myoblasts and critical scientific attention is essential (Bhat et al., 2019; Guan et al., 2021). The culture medium, which accounts for 55% to 95% of the total production cost, is the most major cost driver in the cell-based meat manufacturing process. As a result, in the development and optimization of the cell-based meat manufacturing process, cost reduction remains a top focus (Kolkmann et al., 2020).
The composition of the scaffold poses a comparable issue to cell-based meat manufacturing. For cell adhesion and growth, ideal scaffolds should have a large specific surface area, a flexible contraction and relaxation property, and good cell affinity and compatibility. At the same time, the digestibility, edibility, safety, economics, and scalability of cell-based meat should be considered (Browe & Freeman, 2019). In terms of bio-based scaffold materials, they are commonly classified as non-edible, non-edible but degradable, or edible scaffolds, depending on their degradability and edibility (Bodiou et al., 2020). If degradable scaffolds are used, they must remain stable during the cell growth procedure and be degraded either naturally or artificially before the acquisition of cell-based meat products, so the degradation method and time must be carefully controlled to avoid cell damage or gene and protein expression interferon (Guan et al., 2021). Scaffolds made from extruded gelatin microfibers have been shown to support the adhesion, growth, and maturation of cow and rabbit muscle cells (MacQueen et al., 2019). However, as these natural scaffolds are obtained from animals, their application will fall short of the core goals of cell-based meat. The texture, taste, thermal stability, cooking attributes, and nutritional content of scaffolds must also be examined as part of the cell-based meat products, as well as the cost and availability of scalable production (Guan et al., 2021). The dismantling of the scaffolding system is also a barrier in scaffold-based production. Traditionally, sheets of cells are physically or enzymatically removed from the scaffolding system, causing harm to both the cells and the extracellular matrix created by them, but now certain innovative possibilities are being used to overcome this challenge (Canavan et al., 2005).

Designing and developing intelligent bioreactors for cell-based meat is a technical challenge, with the potential to be the largest in the field of mammalian cell culture. For example, if one ton of cell-based meat is produced, the needed cell number is in the range of $10^{14}$, and the maximum accessible cell density in bioreactors is $1-3\times10^7 \times 0.001 \text{ L}$, the basic configuration is one $10 \text{ m}^3$ or ten $1 \text{ m}^3$ bioreactors (Post et al., 2020). Publications show bioreactor expansion up to $5 \text{ L}$, however, with today's commercially accessible technologies, bioreactors up to $2000 \text{ L}$ are possible (Schnitzler et al., 2016). To put the scale of cell-based meat production into perspective, $8 \times 10^{12}$ cells are required to extract one kilogram of protein from muscle cells, which would necessitate a $5000 \text{ L}$ traditional stirred tank bioreactor. While this amount is common in established bioprocessing, tissue engineering and mesenchymal stem cell growth have yet to be established. Other bioreactor designs, such as fluidized bed bioreactors and hollow fiber membrane bioreactors, can theoretically attain larger cell densities, although they are much less established for cell expansion at this time. Scale-up (in a few big bioreactors) or scale-out (in many smaller bioreactors) are both major difficulties (Stephens et al., 2018). Consumers expect cell-based meat to be as good as, if not better than meat produced by farm animals in terms of color, flavor, texture, and nutrition, so it's structural and biochemical composition must be comparable to regular meat (Bhat et al., 2019).

It's difficult to replicate the flavor of meat in vitro because it comprises over a thousand fat-derived and water-soluble components (Sharma et al., 2015). Due to reduced myoglobin expression in cell-based cells under ambient oxygen conditions, the hue of cell-based meat generated in laboratories today tends to be more yellowish than reddish or pinkish (Post & Hocquette, 2017). Several studies have shown that by
cultured bovine muscle fibers under low oxygen levels, myoglobin expression may be enhanced, causing the hue to shift closer to that of real meat (Kanatous & Mammen, 2010). Many recently produced imitation products on the market use plant-based heme to reproduce the color and flavor of meat, therefore fortification with heme and iron during the processing phase should be addressed. Aside from adding nutritional value, adipose tissue is required for meat texture, juiciness, and flavor, so co-culturing muscle cells with adipose tissue cells is essential. On the other hand, increasing the number of cell types during co-culturing greatly increases the number of test situations, making cell co-culturing experimentally difficult. Furthermore, different cell types have distinct nutritional requirements, and muscle cells mature considerably faster than adipose tissue, which takes two to three months to mature into white adipose tissue. Extensive experimentation and effort will be required to optimize the experimental circumstances. Aside from these factors, there are a few more that influence the development of sensory qualities and meat quality, including biochemical and physical changes that occur during the aging process (Bhat et al., 2019).

Consumer acceptance and perception

The public's perception and acceptance of new technologies and goods is always a challenge, and cell-based meat is no exception (Bryant, 2020). Researchers concluded that individuals have varied opinions about tasting cell-based meat after conducting a systematic analysis based on 14 studies on consumer acceptance of cell-based meat (Bryant & Barnett, 2018). People who are familiar with cell-based meat or who have been educated about the benefits of cell-based meat for the environment and health are more likely to accept it. Consumer complaints are primarily about food safety and pricing, as well as uncertainties such as unnaturalness, unhealthy, unappealing taste, and unexpected price. After that, researchers looked at customer approval of cell-based meat after tasting it, emphasizing the importance of positive information in increasing acceptance and willingness to try it. Surprisingly, 58% of those polled were willing to pay a 37% premium for cell-based meat over normal meat (Rolland et al., 2020).

Existing research on public perceptions of cell-based meat uses a variety of methodologies, but they all find in common that people have a wide range of feelings about it, from extremely positive to very unfavorable, with a lot of middle ground in between. Although cell-based meat is primarily targeted at meat-eaters, it may also appeal to vegetarians who abstain from eating meat out of compassion for animals. As a result, the environmental and animal welfare benefits of cell-based meat should be calculated and disseminated appropriately (Milburn, 2016). Perceived unnaturalness and unappealing qualities of cell-based meat can be a concern, according to social media studies and comments on media articles regarding cell-based meat (Laestadius & Caldwell, 2015). Multiple correspondence analysis identified three unique groups of respondents in a poll of 1890 scientists and students on cell-based meat: those in favor, those opposed, and those who had no opinion (Hocquette et al., 2015). Another online study of 673 people in the United States found that while over two-thirds of respondents indicated they would try cell-based meat, just one-third said they would eat it daily (Wilks & Phillips, 2017). As a result, in addition to pursuing scientific breakthroughs, public science popularization of cell-based meat...
should be carried forth through a variety of channels. The purpose of creation, production technique, advantages and disadvantages of cell-based meat, as well as the nutritional value, food safety, and health effects of products, should all be made available to the general public without prejudice. Consumers can decide whether or not to eat cell-based meat once they have established the correct perception (Guan et al., 2021).

Though some people perceive cell-based meat to be unnatural and reject it, there is a group of individuals who appreciate it since it is animal-friendly, healthy, and safe. Because the contents of meat, such as lipids, proteins, and iron, can be adjusted, it may be recommended by doctors and utilized as a medical diet in the future. People from various religious and cultural origins hold distinct perspectives. Cell-based meat is viewed by some as contempt for God and the environment, while others favor it since it avoids animal murder. Technology acceptability is greatly impacted by public perceptions of technology. Public perceptions can only be changed if the right message is delivered through the right channels, such as media coverage, product introductions in public, and scientists' increasing awareness through debates and conversations about new technologies. Thus, before the commercial success of these goods, governments must work on regulatory rules to aid the acceptance of cell-based meat and to keep a check on quality and purpose (Gaydhane et al., 2018).

**Ethical considerations**

In comparison to synthetic materials, people believe that anything natural is healthy and safe. Growing animal parts in the lab was rejected and despised by the ethical community since it seemed like tampering with God's creation and demeaning the creatures. Some people are also concerned that cell-based meat would eventually replace animal farming, reducing the number of happy farm animals (Bhat et al., 2015; Milburn, 2016; Schaefer & Savulescu, 2014). One of the most important ethical concerns associated with contemporary cell-based meat processing technologies is animal suffering and death.

The current production processes include harvesting biopsies for stem cells from donor animals and using a medium based on fetal calf serum (blood from fetuses recovered from slaughtered pregnant cows). Even though such animal biopsies are thought to be painless (or use tissues like feathers) and research on an animal-free growing medium is ongoing, meat produced in labs and by start-up businesses has yet to be rid of all the animal's quirks.

Another concern with selling cell-based meat is that it is unethical to promote unhealthy food, even if we believe it will be properly farmed in the future. Health experts are highly opposed to promoting items that are damaging to people's health, such as fast food for youngsters or smoking. There is mounting evidence that eating meat, particularly processed red meats, is linked to some cancers and cardiovascular diseases. Because present cell-based meat technology can only make processed meats, promoting cell-based meat would not only put meat at the center of the human diet, but it would also stimulate the consumption of processed meats.
If cell-based meat is claimed to be a necessity for ethically feeding the world's growing population in the future, it would be unethical to divert resources into a system that is less efficient than plants. Moreover, diverting nutrients and plant products directly for human consumption rather than using them to grow cell-based meat would be more effective in avoiding future widespread famine.

Other issues with cell-based meat production include its perceived unnaturalness, the risk of cannibalism, and the fact that it will increase dependency on global food corporations while reducing local self-sufficiency (Bhat et al., 2019).

**Religious restrictions and social taboos**

Religious leaders continue to debate whether cell-based meat is Kosher (kosher for Jewish dietary requirements), Halal (halal for Muslim consumers who follow Islamic standards), and what to do if no animal is available for ceremonial rites (Hindu consumers). The rabbinical viewpoint on Judaism is conflicted. Some feel that cell-based meat can only be kosher if the cells were derived from a kosher animal that had been slaughtered. Others argue that the cells employed to create cell-based meat will lose their original identity regardless of where they came from. As a result, the final product cannot be labeled as unfit for human consumption (Krautwirth, 2018). In the Christian community, the Lord commands in Deuteronomy 14:3-21 of the Holy Bible to list the names of edible animal meat and non-touchable animals, as well as the source of stem cells. "Thou shalt not eat any abominable thing the best you shall eat ox, sheep, and goat". Nonetheless, you are not permitted to eat camels or swine. It has a Jewish connection as well (Mengistie, 2020).

For the Islamic community, the most significant question is whether the cell-based meat is halal, or whether it meets Islamic criteria. Traditional Islamic jurists, whom Muslims commonly consult, have never argued the halal legitimacy of meat culturing because it is a relatively new finding. As a result, present Islamic jurists have taken on this job. The source of the cells and serum medium used in the development of cell-based meat can be utilized to assess its halal status. In vitro meat can only be labeled halal if the stem cells were taken from a halal slaughtered animal and no blood or serum was used in the procedure. Indeed, serum should be avoided unless it can be proven that the meat will not be harmed as a result of its contact with the serum (due to the risk of contamination) (Hamdan et al., 2018). However, Hinduism and Buddhism both contain nonviolent values that advocate a vegan diet, and only a small percentage of Hindus prefer cell-based meat because most Hindus support the humane slaughter of animals for nourishment. Beef, on the other hand, is forbidden since cows are considered sacred (Mattick et al., 2015).

**Regulatory challenges**

Food regulatory agencies must focus on creating guidelines to promote the acceptability of cell-based meat and channel research and development efforts for speedy commercialization. Consumers would
feel more at ease with reference criteria, and entrepreneurs pursuing the commercialization of cell-based meat would have less mistrust (Gaydhane et al., 2018).

The United States Department of Agriculture (USDA) and Food and Drug Administration (FDA) achieved an agreement in March 2019 on each agency's regulatory duties for cell-based meat. In a nutshell, the FDA will be in charge of cell collection and development for harvesting. The USDA will be in charge of overseeing the production and labeling of food products developed from these cells (Food and Drug Administration, 2019). In terms of the worldwide cell-based meat industry's regulatory position, the European Union (EU) was the first to propose it, the United States was the most active promoter, and Israel and Singapore were enthusiastic participants (Listek, 2020; Post et al., 2020). The EU Novel Foods Regulation ((EU) 2015/2283), which took effect on January 1, 2018, specifically classifies goods made by animal cell or tissue culture as new foods, reducing legal stumbling blocks to the selling of cell-based meat (EFSA, 2018). FDA and the United States Department of Agriculture Food Safety and Inspection Service (USDAFSIS) collaborated to establish a regulatory framework to monitor cell-based meat in the US (FDA, 2019). Food Standards Australia New Zealand (FSANZ), a legislative authority responsible for developing food standards for Australia and New Zealand, has announced that cell-based meat may be included in their current Food Standards Code, but that specialist premarket certification is required (FSANZ, 2017). In China, the cell-based meat industry's supervisory structure and necessary legislation are being established and upgraded. According to Chinese researchers, cell-based meat should be treated as a novel food raw material, and handled using the National Management Method for Safety Review of New Food Raw Materials (S. Bonny et al., 2015). The regulatory agency in charge of developing food standards in Australia and New Zealand, Food Standards Australia New Zealand (FSANZ), has announced that cell-based meat may be included in the current Food Standards Code, but that expert premarket certification is required (TingWei et al., 2019).

The safety evaluation and regulatory policy of cell-based meat, as a type of brand new meat product, must be carefully investigated and formulated. The safety of donor animals and the entire cell-based meat production process should be improved, and an independent standard system and an objective regulatory system should be developed to assess food safety risks and nutrient content. Singapore officials claimed to have approved the application of Eat Just to publicly sell a cultured chicken product in December 2020. It is the first regulatory issue for cell-based meat in the globe (Poinski, 2020). The food safety risk of cell-based meat during the production process involves chemical safety, bio-safety, and nutrition security, and no detailed information regarding the texture, flavor, or nutrients of this product, such as the amino acid composition, protein, fat, or mineral content, can be found (TingWei et al., 2019). The use of antibiotics and hormones, as well as the medium components and supplementary additives for cell proliferation and differentiation, should all comply with the relevant rules (Chriki & Hocquette, 2020; Fujita et al., 2010; Schnitzler et al., 2016). Due to their first application in the food industry, several additives require the development of usage specifications for food products. Before premarket approval for cell-based meat, the possibility for gene and protein variation owing to long-term in vitro cultivation should be assessed. If gene modification is used in the manufacturing process, the entire product should be tested for sensitization, toxicity, and tumorigenicity in a rigorous rotation (Edelman et al., 2005;
Mohorčich & Reese, 2019). In a nutshell, food safety evaluation standards and policy regulations aimed at all materials and products in the cell-based meat industrial chain should be implemented as soon as feasible, so that cell-based meat research can be guided.

Cost of production & Economy

One of the major challenges of cell-based meat is its cost of production. Some research groups have recently produced cultured chicken, beef, and marine items on a pilot and larger scale, with costs ranging from $66.4/kg to $2200.5/kg (Scipioni, 2020; Starostinetskaya, 2021). Conventional meat, on the other hand, costs $2.1–3.9/kg for broiler chicken, $5.6–10.2/kg for beef cattle, and $2.7–7.1/kg for pig, which is significantly less than the current cost of cell-based meat (USDA, 2021). As a result, in the development and optimization of the cell-based meat manufacturing process, cost reduction remains a top focus. The cultural medium is the major cost driver in the cell-based meat production process, accounting for 55-95% of the total production cost, because of the need for a chemically defined and animal-free medium, which necessitates the use of somewhat expensive recombinant growth factors in place of bovine sera (Kolkmann et al., 2020; Ng & Kurisawa, 2021).

In vitro meat production will undoubtedly have an impact on the economies of nations that engage in large-scale conventional meat production and rely on meat exports to other countries. In places where cell-based meat production is being introduced on a large scale, this technology will have an impact on agricultural employment. These production centers will cut pollution by being close to cities to reduce transportation costs, but this may not be good for the countryside (Bhat et al., 2015). The initial investment is higher and requires skilled laborers. As this is a risky innovation, traditional banks will be reluctant to give financial support to these developments. Furthermore, the production of cell-based meat is not going to benefit the poor in developing countries soon.

Health safety

The cell culture technique would be a first step toward determining the health and environmental safety of in vitro meat production. The culture medium is provided with nutrients, hormones, and growth factors to maintain cell growth, proliferation, and differentiation in cell culture. However, researchers are unaware of whether these compounds have any short-term or long-term harmful effects on human health (Chriki & Hocquette, 2020). Furthermore, plastic wares used for cell culture, such as culture flasks, culture plates, Petri dishes, and so on, could be a significant source of endocrine-disrupting chemicals (EDCs), as EDCs such as bisphenol A (BPA) and dibutyl phthalate (DBP) are used to provide texture and flexibility to plastic items. As a result of the widespread use of plastic goods in cell culture, EDCs may accumulate in culturing cells that can be in stem cells or matured muscle cells. As a result, doing a toxicological assessment of cell-based meat before commercialization has become feasible (Manikkam et al., 2013; Singh et al., 2020). Eating meat, particularly processed red meat, is linked to some cancers and cardiovascular diseases too.
Environmental

In a survey, cell-based meat was compared against a variety of animal protein alternatives (plant, mycoprotein, dairy, and chicken) by using a different comparison field. The researchers discovered that lab-grown meat had a lower environmental impact than conventional beef and perhaps pork, but a larger impact than chicken and plant protein production, owing to high energy demands, except land use and terrestrial soil and freshwater ecotoxicity (Smetana et al., 2015). According to another study, cell-based meat uses fewer agricultural inputs and occupies less area than livestock, but these advantages may come at the expense of more intensive energy use (Mattick et al., 2015). Cell-based meat may generate more externalities than several meat alternatives, such as gluten, soymeal, or insect-based substitutes, and some components, such as glucose and amino acids, must be present in high concentrations for cell-based meat production, and these components have a significant impact on the environmental footprint (Post et al., 2020; Smetana et al., 2015). Greenhouse gas emissions by the cell-based meat products are compared to three distinct beef production systems. Even though cell-based meat produces far less pollution than cattle, they find that cell-based meat is not always more climate-friendly in one scenario. This is because carbon dioxide (CO$_2$) from energy generation accounts for almost all of the CO$_2$ emitted by cell-based meat, and CO$_2$ lasts longer in the atmosphere than methane or nitrous oxide emitted by conventional meat production. As a result, they conclude that, in the long run, cell-based meat may cause greater climatic problems than beef. However, this conclusion is highly speculative, as the result in the simulations occurs only after hundreds of years. Further research shows that the existing anticipated academic literature on cell-based meat is unreliable. Because the technology is still in its early stages, future emissions will be determined by how manufacturing is finished and scaled, as well as the potential to minimize emissions in other sections of the life cycle. It also emphasizes the importance of combining impact assessments with more coherent scenarios for future renewable energy supply (Lynch & Pierrehumbert, 2019).

According to another study, although greenhouse gas emissions will be reduced by 78-96%, land use will be reduced by 99%, water consumption will be reduced by 82-96%, and energy consumption will be reduced by 7-45% when compared to conventional farming, except for conventional poultry meat, which requires less energy. According to a comparable study, cell-based beef has a lower heating potential than normal beef. However, cell-based pork and chicken meat may require a large amount of energy, resulting in a higher heating potential than conventional products (Tuomisto & Teixeira de Mattos, 2011).

Switching from beef to alternative proteins can result in massive decreases in greenhouse gas emissions, particularly when using plant or insect-based proteins. While current estimates of cell-based meat emissions imply relatively moderate savings only, that also depends on how the production of cell-based meat is scaled up, because depending on that, large reductions in emissions are possible (Godfray, 2019).

| Table 1. Caption |
| Various challenges affecting cell-based meat production (technical, consumer |
acceptance, ethical issues, religious concerns, regulatory aspects, economy and cost of production, health safety and concerns, environmental issues).

Future Prospects And Conclusions

Cell-based meat technology has progressed from a simple concept to a growing number of businesses all aiming to produce cell-based meat for human consumption. Since this idea is still in the works, we believe that a massive shift in animal farming is unavoidable. Furthermore, with the introduction of this technology, a big number of non-meat eaters may be persuaded to eat cell-based meat because it is safe and devoid of animal killing and suffering. Consumers who prefer vegetarianism for ethical reasons will be drawn to cell-based meat. Because in vitro meat production is a controlled and manipulatable technology, it is feasible to adjust the quality of meat to produce "designer meat" on a long-term basis. However, fundamental issues such as cell sources, simulating the in vivo environment of myogenesis, production cost, nutritional quality, texture and taste, and customer acceptance should all be carefully addressed through interdisciplinary scientific interventions (Bhat et al., 2019; Singh et al., 2020).

The very first "Cell-based Meat Symposium," held in Norway in 2008, predicted that the first commercial cell-based meat products will be available within the next five to ten years at costs comparable to European beef ($5,200–$5,500 per ton or $3,300–$3,500) and readily available in supermarkets for each person (Penn, 2018). Moreover, cell-based meat production at a business level even now requires substantial in-depth studies because, in the coming years, cell-based meat will be an integral part of the human diet. However, in the near term, the exceptionally high cost of biologically synthesized meat is the main obstacle to its commercialization, so scientists are trying to dig hard and devote their expertise and time to optimize the overall cost and commercialization (Bhat et al., 2019). To put the past few years in perspective, Mark Post's first burger cost $330,000 to make, and Memphis Meats was manufacturing meat for less than one-fiftieth of that cost within a few years. Mark Post will sell Mosa Meat's burgers for around $10 per patty by 2020, and for around the same price as the least expensive meat on the market five years later (Grass, 2019). Cell-based meat could be produced in countries with little or no agricultural land. It's not surprising, then, that Singapore was the first country to market cell-based meat. Changes in the sites of local and global meat production should restructure economic and social networks in such a way that forecasts are difficult to make now because the location of cell-based meat production and the exact inputs necessary are unknown (Treich, 2021).

Furthermore, external stress factors (management and environment) will be eliminated from meat culturing in bioreactors, resulting in the optimal production of consistent quality meat. This will allow the meat to be grown in areas with unfavorable climates and land. In addition, with the creation of cell-based meat, there will be less waste as in conventional meat production (Bhat et al., 2019). It is thought that if meat substitutes such as Quorn and tofu gain acceptance and people shift to semi-vegetarianism, it will be easier to accept cell-based meat in the future. Practically cell-based meat may not be a quick solution to food shortages. However, since the nutrient composition can be tweaked, its
acceptance as "medicinal" meat may increase. Taste, scalability, and even cost become less of an issue in this instance, just like people don't mind taking vitamin pills instead of eating fruits and vegetables. Traditional animal farming will continue to play a significant role in meeting protein dietary demand. Another ray of hope is growing public awareness and consciousness about the environment, which may entice some people to try cell-based meat (Gaydhane et al., 2018).

Similarly, the meat industry of the future will undoubtedly be more complex than that of today, with a wider range of meat products or meat substitutes accessible on the market from various sources or procedures (Bonny et al., 2015; Bonny et al., 2017). All protein sources have drawbacks and benefits that will influence their commercial viability and customer acceptance (Bonny et al., 2017). To be successful, new products must be commercially viable alternatives to existing meat production. Because customers are likely to refer to items with comparable market positioning, the success of cell-based meat as an alternative, substitute, or supplement to conventional meat will be critical (van der Weele et al., 2019; Verbeke et al., 2015; Verbeke et al., 2015). In 2025, the worldwide cell-based meat market is expected to be worth USD 214 million. It is predicted to reach USD 593 million by 2032 in a normal scenario, indicating a 15.7% CAGR from 2025 to 2032. Entrepreneurs are attempting to break into the market by launching new businesses (Gertenbach et al., 2021). Clean meat marketing is predicted to be available in India by the year 2025.

The Good Food Institute and the Humane Society of India have recently signed MoUs with two institutions: CCMB in Hyderabad and ICT in Mumbai. Researchers at IIT Guwahati have made lab-grown meat and sought a patent on it (Srutee et al, R.S &Uday, 2021).

If in-vitro meat production becomes possible, it will alleviate many of the problems connected with conventional meat production. However, these procedures necessitated the development of bioreactors and the investigation of how well they replicate natural meat in terms of all compositions (structure, morphological, and nutritional value). However, fundamental issues such as cell sources, simulating the in vivo environment of myogenesis, production cost, nutritional quality, texture and flavor, and customer acceptance should all be carefully addressed through interdisciplinary scientific interventions.

Since the Stone Age, when humans used to eat raw meat, meat has been one of the most important sources of nutrients in the human diet. Meat production systems based on cattle take a substantial amount of land, energy, and water. Other considerations include nutritional-related diseases, food-borne illnesses, the emergence of antibiotic-resistant bacterial strains, as well as ethical, religious, and animal welfare concerns. As a result, researchers have been prompted to develop revolutionary meat production systems. Because of the introduction of cutting-edge technology such as traditional and prospective approaches, in vitro meat production has progressed.

Even though cell-based meat is still in its early stages, it is a promising technology that provides a safe and disease-free way to meet rising meat demand without sacrificing animals while also reducing environmental impact and human disease burden. Furthermore, it has the potential to combine a low environmental impact with nutritional and taste attributes that are comparable to conventional meat.
With a rapidly rising global population, cell-based meat would supply healthful, nutritious, and sustainable nourishment for future generations. Food shortages would be alleviated, food-borne infections would be reduced, pollution would be reduced, and the output of cell-based meat would increase. Cell-based meat would reduce the reliance on natural resources and land resources, allowing the area to be used for other productive and recreational purposes. However, there are technical, ethical, religious, regulatory, and public neophobia challenges with in vitro meat that must be addressed before it can be included in the human food chain. In the event of future pandemics, the demand for animal protein sources will increase. In such a time of crisis, in vitro meat would be the best approach to alleviate the food crisis and the best option for improving the human population's nutritious profile through protein-integrated manufacturing protocols.

Declarations

Conflict of interest

All authors declare that they have no conflicts of interest.

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**Figures**

**Figure 1**

Overview of the paper, detailing production techniques, upcoming challenges, and the prospects of cell-based meat.

**Figure 2**

Stem cell technique for producing cell-based meat.

**Supplementary Files**

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