Nutrafoods (2025) 1 629-639 DOI 10.17470/NF-025-0071

Review

Lab-grown meat – a review: The next cellular agricultural revolution

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Abstract

Cellular agriculture, also known as lab-grown or cultured meat, is an emerging technology aimed at producing agricultural products, particularly animal-derived produce, through cell-level processes rather than traditional livestock farming. Products developed in this field present an opportunity to reduce the negative impacts of conventional meat production on human health, the environment and animal welfare. Compared with traditional meat, lab-grown meat can address the increasing global food demand without animal cruelty and significantly reduce greenhouse gas emissions. This study explores the role of cellular agriculture in driving a new meat revolution, based on secondary sources. The main objectives are to assess the impact of lab-grown meat production on traditional meat production across various social, ethical, economic, and environmental scenarios.

Keywords: Cellular agriculture, cultured meat, lab-grown meat, traditional meat, greenhouse emissions.

Introduction

According to the Food and Agriculture Organization (FAO), demand for meat is predicted to increase by up to 73% by 2050 due to rising populations and reductions in poverty. This presents a significant challenge, particularly in terms of resource limitations and land availability [1]. Meat consumption has been steadily increasing in both developed and developing nations [2]. During the second half of the 20th century, global meat consumption grew fivefold, rising from 45 million tons in 1950 to nearly 300 million tons today [3]. With this increased demand, ethical and environmental concerns related to meat production are also expected to escalate in developing countries. Meeting the food demands of a growing population while minimizing the environmental impacts of conventional agriculture is a formidable challenge, necessitating fundamental changes in how food is produced [4].

Lab-grown meat, also called in vitro meat, cultured meat or clean meat, an innovative advancement in animal-based proteins, offers a promising solution. The production of cultured meat aligns with the growing field of cellular agriculture, allowing for the creation of animal products without the need for traditional livestock farming. By avoiding animal slaughter, lab-grown meat can provide a sustainable alternative that meets increasing global food demands while reducing greenhouse gas emissions [5,6]. Cultured meat production also has the potential to improve both the efficiency and the value of meat products [7–9]; incorporating plant protein into animal meat provides a protein-rich and nutritionally balanced food source and is an appealing alternative. Controlling key structural properties will be critical for all applications involving cultured cells. Western consumers, while hesitant to reduce meat consumption [2], are increasingly concerned about sustainability and animal welfare issues [10,11].

India, home to the world's largest population of domesticated animals, faces unique challenges and opportunities. According to the 19th Livestock Census, India has approximately 300 million cattle, 135.2 million goats, 65.07 million sheep and 10.3 million pigs, along with 729.2 million poultry. India is the world's largest exporter of buffalo meat and the third-largest exporter of meat overall. However, livestock production remains inefficient as only around 15% of animal feed is converted into protein. In contrast, pigs and chickens achieve higher feed-to-protein conversion rates [12]. Livestock production also consumes a significant portion of resources that could be redirected towards reducing global food shortages [13].

In this review, we examine how lab-grown meat can address the challenges posed by a growing population. Compared with conventional meat, lab-grown alternatives offer a more affordable and sustainable solution, can be more beneficial to human health, reduce carbon emissions, conserve water, improve animal welfare and support rural industrialization and labour markets. The key characteristics of lab-grown meat, its historical development and its impact on global and Indian agricultural systems and consumer markets are explored and summarized [14]. We also investigate the expected changes in the farming sector from a growing demand for lab-grown meat and analyze the potential of lab-grown meat across four main areas: 1. the process and cost of lab-grown meat development; 2. the advantages and disadvantages of cellular agriculture; 3. societal and ethical concerns; 4. economical aspects [15]. This review aims to enhance understanding of synthetic meat and its technological and economic development, making commercial production feasible and relevant to traditional meat industries.

Historical timeline of lab-grown meat

Several researchers have made lab-developed meats after long stretches of exploration, preliminaries, and uncountable hours of work. In 1998, Jon Vein acquired a patent for the manufacturing of lab-grown meat tissue for human consumption. Three years later, in 2001, NASA started trials, creating cultured meats by starter cells derived from turkeys. In the same year, a patent was filed for a method of creating cultured meat for human consumption by three businessmen: Willem van Kooten, Willem van Eelen and Wiete Westerhof. In 2002, the first edible lab-grown meat, a fish fillet, was produced using cultured goldfish cells. By 2003, the Harvard Medical School and the Tissue Culture and Art Project succeeded in producing frog stem cell tissue resembling a steak. Fast forward to 2009, Time magazine recognized lab-grown meat as one of the year's most innovative ideas.

In 2013 the world's first lab-developed meat burger was made by Dr Mark Post at Maastricht University in the Netherlands. It was consumed during a press event, hosted in London, England. In 2016 Memphis Meats posted a promotion video introducing their lab-developed meatballs. In the same year, Super Meatworks, was on a mission to raise funds to bring lab-grown poultry items to the market. In 2017, Finless Foods declared that they envision bringing practical, lab-developed seafood to consumer markets within two years. In 2018, the Dutch startup, Meatable, developed a method to produce cultured meat from stem cells without killing an animal for the initial cells, addressing ethical concerns about animal welfare [16].

Process and cost of lab-grown meat production

Lab-grown meat is developed in cell culture, rather than taken from an animal's body. The system of in vitro muscle tissue improvement has been practised for more than 100 years. However, it wasn't until 2013 that research group at the University of Maastricht presented a burger made from lab-created meat from bovine stem cells [17]. This interesting burger cost more than $300,000 to make. Two years later, a specialist gathering was prepared to diminish the cost to $11.36 [18]. Despite this, commercial production has not yet evolved and lab developed meat or cell culture meat innovation awaits its place in the rising field of cell agriculture.

Lab-grown meat is produced by extracting adult muscle stem cells from an animal which are then filtered and isolated for cells that can be grown. In principle, these cells can be acquired from any species, however, the details of the production process are distinctive for each. Currently, scientists are developing the technology for at least bovine, pig, turkey, chicken, duck and fish cells (**Fig. 1**) [15]. The cell is then given the proper environment and nutrients like sugar, salt and protein in cell culture to mimic the environment of still being in the animal. The cell will then normally copy, develop muscle, fat and connective tissue – a process which can then transform our food.

Currently, many companies are working quickly to create lab-developed alternatives to rival some of our favourite meat products. The potential for expansion in the lab-grown meat business is backed by investors such as Bill Gates and Cargill rural organization.

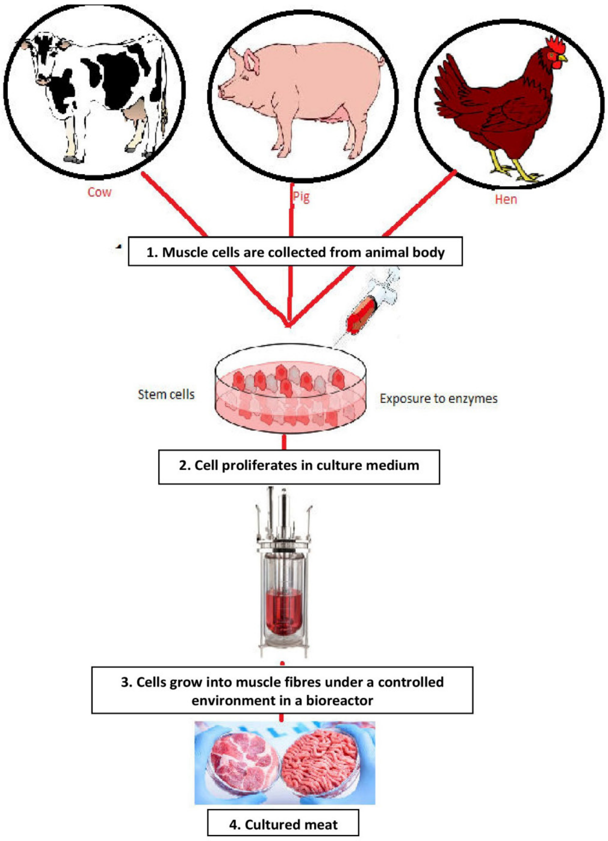

Figure 1: Production process for cultured meat.

- Stem cells are taken from the muscle tissue or embryos of animals such as cows, buffalo, pigs, fish or hens.
- The cells are expanded and then proliferated in culture medium.
- The cells are cultivated in a bioreactor for optimal cell growth.
- The cells are moved to a framework to develop muscle filaments and bigger tissue.

The advantages and disadvantages of adopting cellular agricultural

Positive effect on public health

The progress from conventional animal-derived meat to lab-grown meat may beneficially affect human wellbeing. Most of the saturated fat in the human diet comes from animal produce. It is recognised that a diet high in saturated fat is linked to some medical conditions such as coronary heart disease and stroke. Lab-grown meat offers a healthier alternative as it tends to be adjusted to change the profile of crucial amino acids and fats while retaining the proportions of natural meats. This results in a product with improved nutrients, minerals and bioactive compounds [19]. Saturated fats can be replaced with other fats such as omega-3, furthermore, the proportion between polyunsaturated fatty acids and saturated fatty acids can be easily controlled. The improved nutritional profile of lab-grown meat results in health benefits for the consumer. Furthermore, the introduction of micronutrients in an appropriate matrix, could result in further positive health benefits.

Animals are routinely given antimicrobial medication to forestall sickness. This practice has been associated with the rise in antimicrobial resistance in humans, driving India to introduce guidelines to restrict the use of antimicrobials in cultivation. Lab-grown meat does not require the use of antimicrobials, which may positively affect human wellbeing.

Conditions on some production line ranches and in slaughterhouses can be unhygienic, increasing the risk of illness in humans caused by microorganisms like *Escherichia coli* and *Salmonella* [20–22]. Developing meat in lab conditions can limit this risk.

In the future, a steady increase in the consumption of lab-grown meat and a corresponding decrease in production and consumer costs may make its utilization more reasonable and could build acceptance among both consumers and the agricultural community, helping to moderate certain health deficiencies in the general population and promote physical and mental health in children [22].

Safety

Lab-grown meat is delivered in a climate fully controlled by scientists or producers and requires no other organism interaction. By contrast, animals must naturally be in contact with the outside world. For this reason, supporters of in vitro meat guarantee that it is more secure than regular meat, even though each tissue (including muscle) is protected by the skin, or potentially by mucosa. Certainly, with no stomach-related organs close by (notwithstanding the way that regular meat is for the most part shielded from this), and consequently with no possible tainting at slaughter, cultured muscle cells do not have the same risk of tainting from intestinal microorganisms, such as *E. coli*, *Salmonella* or *Campylobacter* [23] – three microorganisms that are responsible for a huge number of food-related illness every year [24].

Nonetheless, researchers and producers cannot control everything, and any errors or oversights introduce risks. Another positive perspective on the security of cultured meat is that it isn't created from animals reared in confined spaces, reducing the need for exorbitant immunizations against sicknesses like the flu [25]. It is the cells, not the creatures, that live in high numbers in hatcheries to deliver cultured meat.

As in vitro meat is a new product, any potential side effects of cultured meat on the general wellbeing of humans is unknown. A few authors contend that the cycle of cell culture is never entirely controlled and that some sudden biological mechanisms may occur. For example, given the extraordinary number of cell augmentations involved, some dysregulation of cell lines as occurs in malignancy cells is probably going to happen. This is despite the fact that we can envision that liberated cell lines can be disposed of during production or consumption. The possibility of obscure, unexpected consequences for the muscle structure and conceivably on human digestion and health when in vitro meat is eaten cannot be ruled out [26].

Antimicrobial opposition is recognised as one of the most serious issues confronting animals [27]. Refined meat is kept in a controlled climate and close checking can undoubtedly stop any indication of contamination. If antimicrobial use is needed to forestall pollution, even sporadically, or to stop early tainting and disease, this contention becomes less persuading.

Satisfying the need of food for the increasing population

As per figures from the United Nations Food and Agriculture Organization, demand for meat continues to increase and is forecasted to be 70% more than the current level by 2050, as the world's population surpasses 9 billion [1]. We already use the majority of farmland for raising livestock animals. Additionally, water shortage is a growing issue towards which animals contribute considerably. We must consider the fact that we just don't have adequate land and water to sustain a 70% increase in meat production through raising livestock [1]. This infers that we either need to reduce our meat intake or find a more viable approach to produce it. One solution is to substitute meat for plant- or insect-based proteins in the human diet. Humans have eaten meat since the beginning of our advancement [28] and meat is a rich part of various culinary customs. Vegetarian and vegan foods such as veggie burgers and meatballs have so far failed to precisely imitate the intricate flavour and textural profiles of genuine meat and are unsatisfactory substitutes for people who enjoy the taste and texture of meat. Lab-grown meat might be the answer. It is anticipated that lab-grown meat production will utilize 99% less land, and 96% less water [29] than fresh meat. This increased viability offers an opportunity to supply the world's expanding population with certified meat in a maintainable way.

The production process for cultured meat has made significant advancements, including more sustainable methods such as using microalgae-based media instead of grain, which has shown to be up to 10 times more energy-efficient [30]. Additionally, researchers are exploring the recycling of culture media to further reduce waste and improve efficiency, making lab-grown meat a potentially more viable solution to global food shortages [30].

Feasibility and sustainability

The modern livestock industry has one of the world's greatest yet most inadequate food-producing frameworks. However, modern ingredients and food products are now much more efficient. They are about ten times better at using resources like land, water, animal feed, and energy. This means they help reduce waste and make food production more sustainable. Precision fermentation (PF) is a cycle that permits the programming of microorganisms to frame practically any complex organic molecule [31]. The cost of PF has fallen at a remarkable rate due to huge technological advancements. For example, the cost to make a single molecule utilizing PF has dropped from $1 million per kg in 2000 to roughly $100 today. As technology advances, it is predicted that the cost will drop even further – below $10 per kilogram by 2025 [31]. Plant proteins will be multiple times less expensive than customary animal proteins by 2030 and multiple times less expensive in 2035. It is also expected that a new production framework will be available to fuel competition; food items that are consistently less expensive and that offer improved nutrition, taste and health benefits will open market sectors at the same time as nutritional standards are secured [32–33].

Presently, livestock production methods to fulfil the human demand for meat are relatively efficient. Cultured meat production is anticipated to be around multiple times more efficient than conventional beef production. Since stem cells duplicate exponentially, a group of around 150 cows would be adequate to take care of the whole world, versus the 1.5 billion bovines at present on the planet [34]. The conversion rate of feed to animal proteins is approximately 15% for cattle, 30% for pigs and 60% for chickens. To produce 200 g of protein in meat, cattle require 1.33 kg feeding of grain protein. By contrast, lab-grown clean meat can produce 200 g of protein by using just 225 g of nutrients (amino acids, glucose, etc.) [35]. Livestock consumes a large part of our natural food resources that we could otherwise use to directly feed humans, and which could potentially eliminate food shortages at a global scale. Since stem cells are taken from live cattle and proliferated in culture medium, they can become genetically unstable after many divisions. For this reason, several organizations are investigating alternatives for genetic stability with the aim of removing animals from the procedure.

However, Daren Williams, director of communications, National Cattlemen's Beef Association in Centennial, Colorado, USA says that "Beef cattle play a role in a sustainable food system". When a cow is butchered, the remainder of the carcass does not go to squander, we utilize it into a wide assortment of items — industrial, food and pharmaceutical. If lab-grown meat became stunningly successful and replaced meat to a sizeable extent, it will impact the produce that other multiple vendors receive, which will in turn affect the price of downstream products such as leather.

Concerns about the environmental impact of large-scale lab-grown meat production remain, particularly regarding the energy consumption involved. Studies suggest that without renewable energy sources, the carbon dioxide emissions from lab-grown meat could be higher than those from conventional livestock farming [36]. However, the shift to renewable energy would mitigate this issue, making lab-grown meat a key solution to future food sustainability [36].

Instantaneous production of lab-grown meat

Existing customary meat production strategies are ineffectual in terms of nourishment and energy use. The length of time for the meat to be harvested and made accessible in the market is long – months for chickens, a year for pigs and cattle [12]. By contrast, lab-grown meat utilizes an altogether more limited time frame– numerous weeks instead of months for chickens.

Positive impact on the environment

Livestock, explicitly ruminants, contribute to ozone depleting substances or greenhouse gas (GHG) discharge, by releasing methane, which is 30–40 times more powerful than a heat-trapping gas like carbon-dioxide. According to the Food and Agriculture Organization of the UN [1], livestock farming provides up to 15% of all greenhouse gas emissions. Lab-grown meat creates up to 96% less ozone depleting substance emissions, helping us to forestall the disastrous impacts of environmental change [6,7]. The figures are upsetting, even though they offer an opportunity to improve the current production framework to counteract a few of the negative outcomes of meat production. There may be an option to look for a worldwide reduction in meat consumption by empowering vegetarianism or encouraging a restriction on meat. The success of this approach is uncertain, however, given the steady small size of the vegan population in industrial meat‐consuming nations. Furthermore, meat alternatives from vegetable protein sources, have not, up until this point, been able to attract a significant slice of the overall industry outside the conventional vegetarian target population [37]. Despite environmental change, animal production has a specific number of other extreme effects on the climate, like mass deforestation, which is due to required land to raise and nourish animals. This causes a huge and serious loss of biological diversity, and the destruction of 50,000 species every year. Agricultural pollutions are another issue caused by the delivery of wastes like pesticides and composts into over-burdened streams, which then run into our waterways and seas, harming aquatic life. The production of lab-developed meat is noteworthy in that doesn't utilize compound substances and is completed in a closed system, avoiding overflow going into the natural habitat [12].

Impact on water usage and water pollution

Water wastage is a huge issue across the world and big issue in the creation of conventional meat. Lab-developed meat will extraordinarily diminish the amount of water wastage, as it requires only 95 litres of water to produce one pound of meat in comparison to traditional meat, which requires more than 9,085 litres per pound for feed production, animal rearing, and hygiene [38]. Presently animal manure is responsible for around 33% of global nitrogen-phosphorus, 50% of antibiotic pollution, and 37% of toxic heavy metals pollution. We may save more water simply by not eating customary meat [6]. Lab-developed meat is made in a lab; it eliminates the requirement for animals, which can reduce energy usage by up to 45%, reduce land usage by 99%, reduce water usage by 96% and produce up to 96% less ozone harming substances, compared with traditional meat production. Hence, the environmental effects of lab-grown meat production are significantly lower than traditionally produced meat.

Animal cruelty

Around 35 billion animals are farmed yearly all through the world. Such animals are treated more like cogs in a wheel than living creatures. They endure a short, hopeless life and are regularly pressed together in enclosures, pens or containers to an extent that they cannot participate in the daily routines of life [39]. A few animals are reared in a way that causes them to develop quickly, resulting in debilitating conditions, crippled and cracked bones, contaminations and numerous organ failure. Lab-developed meat does not require animals to be butchered for meat; it is created by developing cells that are separated from a live animal utilizing a small biopsy done using anaesthesia, which does harm the animal in any way. Lab-developed meat can therefore stop the suffering of billions of animals every year.

Impact on approach to farming

If the idea of lab-grown meat becomes a reality, the processes that are presently being utilized in the farming sector must undergo critical changes. Lab-grown meat will mean that farmers will be able to focus more on quality than quantity, which often means gathering animals in cruel conditions to increase profits. The cultivation processes in large and commercial farms will also be affected. It is anticipated that an acceptance of lab-grown meat, will result in a significant decrease in livestock numbers. The quicker production time for lab-grown meat makes this possibility a likelihood. Large-scale production of lab-grown meat is probably still a few years away and hopefully, by the time the new processes have been embraced, the necessity for livestock will have gradually decreased and population numbers will be naturally lower. Regarding concern for any unfavourable effects a move to a lab-grown meat may have on farmers, lab-developed meat offers another industry and new opportunities to develop produce that can be utilized in cell farming [12,40].

Consumer acceptance of lab-grown meat– social and ethical concerns

Customer discernment and moral concerns are an important and expected hindrance to the commercial success of lab-grown meat [26]. Presently, consumers find it hard to comprehend that foods grown in a lab will have, as much as could be expected, comparative sensory and organoleptic qualities (taste, surface and appearance) with the natural product [41].

The production of an entire muscle is the objective of lab-grown meat. This requires an unpredictable framework that includes various kinds of cells fused together in a coordinated way, and a structure that will require a reproducible vein organization. A less complex and more achievable objective is the creation of a muscle protein that is part-dependent on muscle cells alone.

Among the genuine advantages of lab-grown meat is the subsequent decrease in the number of meat-producing animals as calculated in international literature [18]. It is a misrepresentation to think that animal numbers will be adequate to meet the meat needs of the growing human population, but it is viable and reasonable that a reduction in the number of animals needed for meat production would bring about improved cultivation methods and better conditions for rearing livestock [15].

One more significant ethical issue is the animal source stem cell donors, as these cells must be gathered from a live or dead animal source. The vital intrusive procedure to obtain the correct sort of muscle tissue might be painful. Additionally, the fundamental serum for the development of cell mass should be taken from an adult, baby or foetal animal source. In the future, this could be replaced with plant extracts such as mushroom extract, which accomplishes higher development rates contrasted with foetal cattle serum and is more economic [42]. Nonetheless, for vegetarians, vegans and other individuals opposed to the use of food and produce of animal origin such procedures can be an ethical obstacle. In terms of innovation and its application, ethical rules are acknowledged and considered against expected advantages or risks. Consumer information on lab-developed meat is at present exceptionally poor. Despite this, reviews show that most consumers are hesitant to answer when asked if they would try lab-grown meat in the future; only a small minority completely dismissed the idea [43,44].

Economical implications

There are many immediate and longer-term consequences for the agribusiness economy from a move towards more lab-grown meat including changes to production processes, cultivation, administration and general labour [17]. Technological developments may be dependent upon a nation's economic standing. By continuously transitioning from traditional farming to manufacturing farming, rural labour development advanced to the current food manufacturing sectors [12].

Conclusion

The advancement of lab-developed meat from animal stem cells by utilizing genetic engineering procedures is an imaginative innovation with a several advantages. Consequently, sustainable alternative technology of protein production is currently being developed to maintain increasing global food security concerns and compliance with the current challenges, such as dealing with a broad range of environmental and animal welfare concerns. By protecting agricultural assets, such as reducing key sources of water and air pollution, lab-developed meat will minimize the ecological impacts of food production and will add to a wide range of sustainable objectives.

Moreover, consumers should acknowledge lab-developed meat as an important and attractive alternative to traditional meat products. Lab-developed meat diminishes the carbon emissions of the food framework, shielding against environmental change. Also, eliminating manure and antibiotic growth agents will assist with improving the health of rural communities, restore waterways, and assure the viability of life-saving medications. There is the additional advantage of creating new jobs in cellular agriculture field. Present lab-developed meat processes are equipped for large commercial production at a reasonable price to the consumer. Further efforts are required to reduce production costs and therefore consumer prices to make lab-grown food products more affordable compared with animal-based meat products. Educating consumers on the safety, security and benefits of lab-grown meats is also needed. The reality of food security crises in the future justifies the genuine innovative work and development being done to bring lab-developed meat to the market.

Conflict of interest

All the authors declare that they have no conflicts of interest.

Consent for publication

All authors give our consent for publication of this review article as it does not involve individual participant data.

Ethical approval

We confirm that this review article does not involve original research with human or animal subjects.

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