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Feeding 10 Billion: Cultured Meat as a Sustainable Protein Source for a Growing Population

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Introduction

Topic overview

The current meat production practices are unsustainable in the fulfillment of the projected demand for protein. Given the increasing global population in the context of limited environmental resources and a changing climate, alternatives to livestock meat must be further examined and developed. Animal-based protein products currently play an instrumental role in providing much of the population with essential nutritional sustenance (Winders & Ransom, 2019). The need to substitute conventional meat with more sustainable alternatives for a growing population under current and future resource constraints is summarized as current practices are correlated with "large use of land, resources, and high GHG footprint along with inefficient nutrient conversion and biodiversity loss" (Jiang, Ameer, Kim, Lee, Ramachandraiah, & Hong, 2020, p. 14).

Given the current unsustainability of conventional meat production and projected population increases, the significance of innovative, resource-efficient alternatives cannot be overlooked. Cultured meat has the potential to address these limitations and provide a sustainable source of protein to simultaneously feed 10 billion people and mitigate the effects of climate change.

Biological importance

Cultured meat, or lab-grown meat, is edible muscle tissue derived from animal muscle cells which are proliferated in a lab setting. Generally, cultured meat is produced by obtaining stem cells from livestock muscle tissue, embryos, or induced somatic cells. The cultured cells are placed in a bioreactor for amplification and a specific media, typically fetal bovine serum, that aids in the proliferation and growth of muscle tissue is introduced. Depending on the desired tissue type, varying methodologies can be implemented to cultivate, amplify, and proliferate the stem cells (Post, 2012).

Societal relevance

To optimize protein supply for a global population of 10 billion, the respective environmental and societal impacts of traditional meat production and cultured meat are vital to assess. The resource requirements of meat production contribute to climate change and food insecurity on a multifaceted level. The global deforestation and environmental degradation associated with conventional meat production limits the ability for other food sources to be cultivated, exacerbating global food insecurity while simultaneously contributing to greenhouse gas emissions (Alexander, Brown, Arneth, Dias, Finnigan, Moran, & Rounsevell, 2017; Pelletier, Pirog, & Rasmussen, 2010). As the ability to curate adequate and accessible protein sources is essential to mitigating global food insecurity, sustainable alternatives that do not inhibit the production of other food derivatives are critical to develop. The discrepancies in annual beef consumption between the average American (124 kg) and the average global citizen (31 kg) based on disposable income emphasize the need for sustainable sources of protein for a growing and developing population (Fiala, 2008). Cultured meat could be implemented as a viable alternative to address the multifaceted concerns associated with the continuation of conventional meat production while simultaneously providing animal-based protein products.

Presentation of research

Historical development

Cultured meat was first brought to the forefront of scientific research when NASA funded an experiment that produced an edible *in vitro* fish filet as a viable protein source for astronauts on long space voyages. The study drew upon methodologies initially developed for the curation of bio-artificial muscles utilized for medicinal research and tissue and organ implants. The authors hypothesized that cultured meat could be employed as a means of providing a continuous supply of consumable animal muscle protein for long-term space crews.

This hypothesis was tested by establishing non-homologous co-cultures of fish explants which is “a cell cultivation set-up, in which two or more different populations of cells are grown with some degree of contact between them” (Goers, Fremont, Polizzi, 2014, p. 1). The non-homologous co-cultures were used to examine the presence of interaction and communication between fibroblasts and skeletal muscle tissue of fish species. Researchers mimicked the constraints of space travel by replacing fetal bovine serum (FBS) with media containing fish meal extract or mushroom extracts. This specific substitution allowed for adult muscle tissue adherence, attachment, and growth onto an explant to be observed over extended periods of time emulating the conditions of a space voyage in these alternate media. Explant behavior under a range of media including fetal bovine serum, fishmeal extract, and mushroom extracts, was measured by percentage increase in area to determine optimal proliferation conditions.

Explant growth measurements were recorded every day for seven days. Following final measurements, the explants were harvested and prepared for a food panel to inspect and critique. The explants were glistening, firm, odorless, and physically resembled fish filets that can be purchased within grocery stores. Moreover, they acted in the same manner as fresh fish would when they were cooked. The FDA regulations at the time prevented tasting of the fish; however, it was deduced by a food panel that the explants were acceptable as food and that implementing an *in vitro* muscle production system for meat protein is a viable option for a means of meat production (Benjaminson, Gilchreist, & Lorenz, 2002).

The production of edible fish explants resembling traditionally cultivated fish filets was the first step in initiating a paradigm shift about current and future meat production practices. The results of this experiment catalyzed the development of cultured meat practices, as scientists drew from this methodology and established more advanced and sustainable *in vitro* techniques. This experiment has pushed the scientific community to examine how skeletal muscle mass can be cultured on a large scale to serve as a protein alternative for food insecurity. NASA's initial experiments established the scientific legitimacy behind cultured meat, allowing further research initiatives addressing the feasibility of utilizing cultured meat as a food source to take place. These developments culminated in the first *in vitro* beef burger being produced and eaten in London in 2013 (Stephens, Di Silvio, Dunsford, Ellis, Glencross, & Sexton, 2018).

Since these preliminary experiments, various types of technological advancements have been developed and examined for their efficacy in large-scale meat production. Furthermore, practices needed for the development of higher-end meat products that are derived from varying tissue types are being investigated. These initial experiments were integral in establishing the legitimacy of cultured meat production as well as an understanding of both the biological mechanisms and potential societal impact of in vitro meat production.

Current status of research

Environmental impact

Cultured meat provides a potential strategy to address global food insecurity by increasing protein output while decreasing required land, resource, and energy inputs. The simultaneous limitation of resources and growth of demand as the global population reaches 10 billion highlights the importance of examining the sustainability of cultured meat production and consumption. Specific metrics of environmental impact include land, water, and energy requirements, as well as greenhouse gas emissions (GHG) (Lynch & Pierrehumbert, 2019; Mattick, Landis, Allenby, & Genovese, 2015). These key measurements provide insight into the long-term sustainability of conventionally produced meat and cultured meat for comparison.

Land use is a specifically complex metric of evaluation as conventional meat production processes currently utilize “30% of global ice-free terrestrial land” for raising, slaughtering, and feeding livestock (Tuomisto et al., 2011, p. 6117). Current conventional meat production and consumption practices are not sustainable for a growing population and subsequent protein demand. Research suggests that if the global population adopts a high animal consumption diet that mimics the average American diet, the requirement for agricultural areas for food would increase by 178% (Alexander et al., 2017, p. 29). The substantial land requirements for the current practices of livestock meat production pose a threat to global food security.

Multiple studies examine land use stipulations for production processes of both conventional meat and *in vitro* meat. In a comparative life cycle analysis, researchers identify the reduction in land usage for *in vitro* meat production as a benefit over conventional production of beef, pork, and poultry (Mattick et al., 2015). Further analysis of global meat production and livestock feed assumptions in relation to land usage indicates "replacing livestock protein with *in vitro* technology would require only 0.07 million km^2 land which is about 0.2% of the current land area that is used for livestock production" (Zhi-Chang et al., 2015, p. 238). The increased land-efficiency of *in vitro* meat production suggests increased sustainability.

The analysis of cultured meat is imperative for a growing global population based on the significant water usage for conventional meat production. Current meat production practices utilize 8% of global freshwater for both livestock hydration and croplands dedicated to livestock feed (Tuomisto et al., 2011). The current rate of freshwater depletion contributes to global food insecurity, as water availability is imperative in preserving "humanity's ability to meet the future food and energy needs of a growing and increasingly affluent human population" (D'Odorico, Davis, Rosa, Carr, et al., 2018, p. 456). This current unsustainable depletion of water emphasizes the need for the development of alternative protein sources.

Given its water-saving benefits, *in vitro* meat production is a critical system to explore in order to provide a sustainable source of protein for a growing global population. Comparative studies on the water requirements of various protein production methods point to the advantages of replacing conventional meat with *in vitro* meat. Production of 1000kg of cultured meat utilizes 82-96% less water than meat from conventionally raised beef, sheep, pork, and poultry (Tuomisto et al., 2011, p. 6117). This outperformance suggests the viability of *in vitro* meat as a sustainable water-preserving protein alternative.

Energy resource usage is the third metric of environmental impact that is relevant to the comparative sustainability evaluation of conventionally produced and cultured meats. Tuomisto & Mattos (2011) found that cultured meat requires 26-33 GJ of energy per 1000 kg of tissue produced, which is 7-45% lower than livestock meat production, depending on animal protein compared with the exception of poultry which had the lowest energy requirement (p. 6117). In contrast, a different analysis of industrial energy consumption across protein production processes concluded *in vitro* meat production requires "substantial energy" in comparison to other livestock meat production processes (Mattick et al., 2015, p.11945).

The majority of industrial energy required for *in vitro* meat production is primarily allocated to the cultivation process, specifically the energy-intensive production of basal media and cleaning (Tuomisto & Mattos, 2011; Mattick et al., 2015). Potential increased energy usage in cultured meat is further attributed to the technical substitution for the biological processes of digestion and nutrient circulation that is traditionally performed by livestock in conventional meat production (Mattick et al., 2015). Current research comparing the industrial energy requirements of livestock meat and cultured meat indicates calculations “are based on many assumptions and, therefore, have high uncertainty” (Tuomisto & Mattos, 2011, p. 6120). Increased uniformity and consistency of measurement would allow more conclusive environmental impacts to be determined for various protein production methods. Current discrepant conclusions on the relative environmental impact of conventional and cultured meat point to the variation of energy usage between different culturing techniques, and the potential for improved efficiency and reduced environmental impact (Tuomisto & Mattos, 2011; Mattick et al., 2015). The energy-intensive components of *in vitro* meat production indicate that sustainable production to feed a global population is contingent on the optimization of current culturing practices to mitigate industrial energy requirements and long-term environmental impact.

A final key metric of overall environmental impact is the respective greenhouse gas (GHG) emissions generated by the production processes of livestock meat and cultured meat. As the growing global population requires animal protein for food, cultured meat could present a strategy to simultaneously address this demand and mitigate GHG emissions in an effort to provide a more sustainable protein source (Fiala, 2008). Current livestock meat production generates 15-24% of the global greenhouse emissions, incurred mostly by the deforestation required for the provision of cropland for livestock feed (Fiala, 2008).

Analysis of cultured meat production indicates the potential for a substantial reduction in GHG emissions on a global scale based on its lack of requirements for deforestation, methane emissions from livestock, and manure management (Datar & Betti, 2010). This mitigated environmental impact has been quantified to range 78-96% lower greenhouse gas emissions in comparison to conventional meat depending on the type of livestock compared to (Tuomisto & Mattos, 2011, p. 6117). A separate quantification of carbon footprints of conventional meat production systems supports the assertion. The respective CO_2-equivalent emissions of cultured meat, poultry, pork and beef were calculated and ranged from 1.9-2.2, 10-30, 20-55 and 45-640 CO2-eq per kg-1 of meat produced, respectively (Jiang et al., 2020; Nijdam, Rood, & Westhoek, 2012; Tuomisto & Mattos, 2011; Zhi-chang, Quin-li, & Lin, 2015). Lynch & Pierrehumbert (2019) highlight the long-term chemical behavior of respective emissions as a further avenue of research that is relevant to the calculation of conventional and cultured meat's environmental impacts. The emissions from cultured meat were found to be almost entirely carbon dioxide (CO_2) while conventional meat generated multiple greenhouse gases but primarily methane (CH_4) emissions. Researchers point to the need for complex GHG emissions evaluation as the accumulation of CO_2 could present long-term increased global warming in comparison to CH_4, which does not accumulate. Discrepancies in methods of analyzing and comparing GHG emissions specifically demonstrates the multifaceted, interconnected elements of environmental impact analysis and need for future studies. While the documented inefficiencies and unsustainability of current livestock meat production emphasize the need for sustainable alternatives, further studies are required to conclusively quantify the relative degree of reduced environmental impact of cultured meat.

Production optimization

Key technological advancements have contributed to the potential integration and commercialization of cultured meat as a sustainable protein source to address food security on a global scale. Impact analyses of these critical developments indicate the technology's ability to mitigate the documented negative impacts of conventional meat production by increasing scalability (Alexander, 2017; Choi, Kim, Yoon, Jeong, Ryu, Jo, & Lee, 2020). These advancements include the development of large-scale bioreactors and optimizing culture conditions to produce tissue that closely resemble traditionally curated meat.

Addressing or partially addressing the global demand for protein with cultured meat is dependent upon the efficacy of bioreactors in large-scale production. Various bioreactors have been evaluated on their ability to effectively produce scalable cultured meat in an economically favorable manner. Stirred-tank bioreactors that are designed utilizing the Computational Fluid Dynamic (CFD) model are optimal for large scale production, as they allow for minimal irritation to the suspended cells within cultures (Zhang, Li, Liu, Zhou, Chen, & Du, 2021; Li, Zhang, Zhao, Zhou, Du, & Chen, 2020). In order to effectively culture skeletal muscles from stem cells, it is imperative to maintain the maximum number of cells from the starting batch of cells in the proliferation phase. This maintenance allows for the preservation of the replicative capacity of satellite cells while simultaneously producing sufficient cells ready to differentiate into skeletal muscle cells with maximum protein production (Post, 2012). Researchers developed a cost-efficient 300m^3 air-lift bioreactor following the CFD model that optimizes the maintenance and mass transfer of cultured meat cells. This bioreactor addresses the demand for large-scale meat production, as it has the potential to supply enough meat for around 75,000 people (Li, et al., 2020). Developing bioreactors with the capability of preserving the bioavailability of meat cultures on a large scale ascertains the viability of cultured meat as a feasible alternative to livestock meat production.

For the substitution of conventionally produced meat with *in vitro* meat to be impactful on a global scale, the final cultured tissue must be indistinguishable in terms of traditional taste, quality, texture, and tenderness. Specific culturing mechanisms and conditions mitigate discrepancies between final products of livestock and lab-grown meat.

In order to achieve cultured meat that closely resembles traditionally produced livestock, induced apoptosis of cell cultures serves as a viable option for addressing texture concerns. Meat tenderization and post-meat quality can be partially attributed to apoptosis under hypoxic conditions. As oxygen is diminished within the cell, energy output changes from aerobic to anaerobic resulting in a decrease in pH due to lactic acid accumulation (Redshaw & Loughna, 2012). This series of biochemical and structural changes is present in post-mortem animal muscle cells. Varying caspase and caplin proteins, including *Caspase 7, 12, HSP70*, and *HSP90,* have been identified as playing a pivotal role in satellite cell myogenesis and induced cell death under hypoxia conditions resulting in proteolysis and meat tenderization (Yang, Pandurangan, & Hwang, 2012). Identification of these proteins is crucial in optimizing production of *in vitro* tissues with a tender texture mimicking that of muscle tissue following slaughter.

Visual appeal and similarity to livestock meat is a critical determinant of consumer familiarity, willingness to try, and acceptance of cultured meat as a source of food (Bryant & Barnett, 2018). Interventions in the production process allow developers to manipulate coloration of cultured meat tissues to imitate that of conventional livestock meat. Precise mimicry of the coloration of livestock meat is accomplished by strategically lowering ambient oxygen levels during the production as a method of increasing myoglobin expression. This reduction of oxygen levels during the culturing process results in an alteration of the relatively yellow tint of cultured meat into a reddish, pinkish tint observed in conventional livestock meat. The color of tissue can be manipulated during the production of *in vitro* meat to closely emulate the traditional cuts of meat consumers already perceive as familiar, natural, and safe. The enhanced myoglobin activity produces a final red and pink-tinted tissue product designed to elicit a more positive response from consumers upon visual analysis (Jiang et al., 2020). Optimizing culture conditions by lowering oxygen to manipulate cultured meat tissue tint is a key technological development used to promote global implementation.

Consumer acceptance

The potential integration of *in vitro* meat as a viable protein source for a growing global population is contingent on consumer acceptance. Market research identifies specific factors that influence acceptance including demographics, framing initiatives, perceptions of health and safety, and overall familiarity.

Gender, age, and level of meat consumption were specific consumer demographics that resulted in statistically significant differences in consumer willingness to try and accept cultured meat as a viable conventional meat substitute. On average, men were generally more willing than women to have a positive perception of *in vitro* meat safety, taste, benefits for society, and capacity to replace conventional meat. The youngest and oldest groups of consumers analyzed had a more positive view of cultured meat in comparison to middle-aged consumers. In a comparison of consumers with different diets, meat-eaters had significantly more apprehension regarding its similarity to livestock meat than non-meat eaters. Evidence on consumer demographics and respective attitudes presents a potential strategy of leveraging early adopters in the global scaling of cultured meat (Bryant & Dillard, 2019).

The influence of framing surrounding cultured meat is a determinant of the efficacy of its positioning as a livestock meat alternative. As an emerging technology with the potential to have global impacts, cultured meat has a diverse range of connotations amongst decision-making consumers. Commonly cited consumer objections to cultured meat pertain to perceptions of the final product as unnatural, expensive, unsafe, unhealthy, dissimilar to conventional meat taste and texture, as well as detrimental to the livelihood of traditional farmers. Consumer support for the integration of cultured meat into the global food supply was most notably observed in perceptions of the final product mitigating environmental impacts of production as well as providing a more accessible protein source for impoverished populations (Bryant & Barnett, 2018). Framing of these critical consumer values was shown to have a statistically significant impact on consumer acceptance of cultured meat. Consumer's beliefs that cultured meat could potentially address food insecurity, promote sustainability, and taste the same as conventional meat led to positive associations. Consumers responded negatively to the positioning of cultured meat as high-tech (Bryant & Dillard, 2019). These values of consumer acceptance are critical to engage in consumer education through phases of cultured meat commercialization.

Moreover, cultured meat potentially serves the need for "cleaner" meat, as research suggests that traditional animal farming is a threat to human health. Intensified farming systems have cultivated an ideal environment for zoonotic diseases to prosper on a multifaceted level due to the high density, high genetic similarity, and immunosuppression of animals. The development of resistant strains of antimicrobials, ventilation of contaminated air, spread of animal waste on lands, biodiversity losses, and increased contact with humans associated with livestock farming also contribute to the spread of zoonotic diseases (Espinosa, Tago, & Treich, 2020; Arshad, Javed, Sohaiv, Saeed, IImran, & Amjad, 2017). The requirements of traditional livestock methods have resulted in pathogens with antimicrobial properties having a higher probability of mutating and evolving, increasing the risk of transmission to humans. This risk is enhanced by the loss of biodiversity associated with traditional meat production (Espinosa, Tago, & Treich, 2020). Implementing cultured meat production to address the global demand for meat products limits the opportunities for zoonotic diseases to emerge. This evidence on consumer health and safety could be influential in driving global acceptance and demand for cultured meat.

Relevant framing specifically focuses on cultured meat through the lenses of potential societal benefits, scientific technology, and similarity to conventional meat. While framing surrounding these specific factors is an imperative practice to gain traction in the protein alternative commercial market as technological advancements are developed, research suggests its influence may be outweighed by familiarity. Despite the lack of statistical analysis on the degree of impact, evidence suggests increased exposure leads to increased acceptance with consumers regardless of connotations implied (Bryant & Barnett, 2018).

Areas of disagreement or lack of knowledge

Although studies presented cultured meat as an environmentally sustainable substitute for conventional meat, disagreement persists regarding the precise quantification of cultured meat's environmental benefits over conventional meat production. Discrepant and conflicting results from various studies regarding the quantified environmental impacts hinder the ability to form objective conclusions about cultured meat's efficacy to relieve hunger.

Moreover, the large-scale impacts and potential benefits of cultured meat on a global scope remain hypothetical values. Thus, direct comparison with current globally scaled conventional meat production is based on projections. The lack of empirical evidence derived from a global-scale production of cultured meat highlights the potential inaccuracies of cultured meat's documented benefits, such as environmental sustainability, cost efficiency, and scalability to supplement current protein production systems.

Large scale production of cost efficient cell culture media has yet to be solidified. The use of muscle cell culture media to produce cultured meat is currently an unsustainable practice and barrier to the implementation of cultured meat into the diets of a global population. The obstacles to scaled substitution of cultured meat for livestock meat is summarized, “muscle cell culture media are expensive, in fact prohibitive on the large scale, therefore, the manufacture of a sustainable, animal-free, affordable media is a major challenge” (Stephens et al., 2018, p. 160). This concern has been addressed through experimentation with media containing fetal bovine serum substitutes of mushroom and fish meal extracts were used in an effort to reduce costs (Benjaminson & Lorenz, 2002). The industrial energy-intensive, animal-product reliant, and costly utilization of muscle cell media in the creation of cultured meat tissue presents current scaling limitations. Feasible scaling of this technology is dependent upon more rigorous analysis of identifying cost-effective culture media.

There are additional discrepancies within the documented feasibility of developing high-quality cultured tissue resembling traditionally produced meat products. Developing these products is dependent on the ability of varying cell types, such as adipocytes and skeletal muscle cells, to proliferate in a co-culture system. The potential for culturing tissues derived from multiple cell types may be limited. A study examining communication between adipocytes and muscle cells within a co-cultured system documented myoblast differentiation's suppression due to their close proximity to adipocytes. This suppression resulted in overall muscle cell development inhibition (Seo, Suzuki, Kobayashi, & Nishimura, 2019). However, supplemental research indicates that technological advancements, like high-pressure treatments (HPT), could potentially mitigate the quality defects of low-fat meat products. High-pressure treatments alter the covalent bonds within proteins, ultimately modifying the molecule's secondary or tertiary structure. These modifications have been found to improve both the texture and juiciness of the product (Xue, Wang, Yuan, Guanglian, Minyi, Xinglian, & Guanghong, 2020). The uncertainty surrounding cultured meat derived from varying cell types affects the assessment of cultured meat's limitations in superseding conventional production.

Conclusions and recommendations

Prior to effective global implementation of cultured meat as a means of addressing food insecurity, additional quantifiable research of the environmental implications from large-scale production is paramount. As current research points to areas of disagreement about the feasible scalability and environmental restoration effects of cultured meat, food insecurity benefits have yet to be definitively quantified. The early-stage nature of cultured meat technology presents challenges in accurately summarizing the degree of impact of addressing global food insecurity sustainably (Stephens et al., 2018). Based on the current ambiguity in the comparative analysis of conventional and cultured meat, life cycle assessment studies are specifically recommended to evaluate existing evidence on benefits over the entirety of its implementation (Jiang et al., 2020). Increased uniformity and rigor of environmental impact analysis would promote feasible implementation into the global population's diet as a meat protein source that supersedes conventional meat.

Additionally, there are multiple technological advancements that must be met for the successful scaling and implementation of cultured meat as a sustainable protein source for the growing global population. The vast majority of current cultured meat production practices require cost-prohibitive media (Stephens, et al., 2018; Choi, Yoon, Kim, Lee, Jeong, Ryu, Jo, & Lee, 2021). Moreover, media and scaffolding required in culturing processes rely on animal-derived products for cell proliferation. Additional optimal cell growth occurs under conditions in which the scaffolding is composed of animal-derived materials. The current scalability of cultured meat to make a global impact is impeded by the inability to remove animal harvesting completely from the production equation (Stephens et al., 2018). Based on these current significant production constraints, future research must prioritize alternative methods of cell harvesting that strategically implement non-animal based, less expensive materials and techniques. Developments in maximizing cell proliferation capabilities would be transformative in promoting the feasible scalability of cultured meat. Without investment in these critical technical avenues of research, the benefits of cultured meat are impossible to capture on a global scale. Based on the evidence of current meat culturing capabilities, innovative technical advancements to increase efficiency in production and cost must be the immediate priority of researchers to drive potential substitution for conventional meat.

Furthermore, technological research and development initiatives should be centered around furthering consumer acceptance of cultured meat. A lack of consumer acceptance would prevent the potential benefits of cultured meat from being meaningfully realized. Based on current evidence on consumer acceptance as a determinant of potential impact, the mimicry of livestock is an essential avenue of research to pursue. To drive consumer acceptance, future studies must leverage both current and emerging techniques to render conventional meat and cultured meat as indistinguishable as possible. Current research indicates the critical efficacies of hypoxia apoptosis via induced caspase activity, lowering oxygen levels, and implementation of co-culture systems to emulate livestock meat tissue. The ongoing optimization of cell culturing conditions is pivotal in maximizing consumer acceptance and thus feasible implementation on a large scale. Any effort to scale and sustainably feed 10 billion people by supplementing animal-protein derivatives with cultured meat is contingent on consumer acceptance, this avenue of research must be leveraged in future studies as the solution is developed.

The implementation of cultured meat is contingent upon its ability to meet projected impacts in both biological and social facets. The intersectionality of global food insecurity and climate change emphasizes the exigent nature of this emergent field. The potential solutions posed by cultured meat are enhanced by the successful rendering of cultured meat products that sustainably address the current biological and societal constraints. Cultured meat has the potential to solve financial, environmental, public health, and food security issues on a global scale. Once technological and scalability advancements are made, cultured meat can be utilized globally as a protein source for the anticipated 10 billion people, mitigating the multifaceted issues that result from traditional meat production.

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