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The potential for cultured meat: a structured literature review of key value chain factors and recent developments in Singapore, India, and Australia

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Abstract

The share of animal protein in consumer diets has increased in developing countries due to growing affordability and remains high in developed economies. The subsequent pressure on supply has encouraged research into producing meat under controlled laboratory conditions. Much of the justification for this trend is that it would lead to fewer externalities arising from the traditional livestock production system. Currently, though, well-funded research by an increasing number of companies across the world has yet to place a commercially viable product on supermarket shelves. Parallel research on consumer acceptability covers aspects of sustainability and enhanced nutrition, whilst also highlighting limitations to its reception. Available analysis details the heterogeneity in consumer perceptions and the subsequent challenges to successful acceptance. Establishing the value chain for cultured meat is a collaborative effort by multiple actors, subject to a country's development status. The aim of this paper is to review important factors relating to the market development for cultured meats through a discussion of challenges and opportunities for growth and the presentation of case studies of developments in three different countries.

Key words: cultured meats, sustainable animal protein, consumer perceptions, India, Australia

Introduction

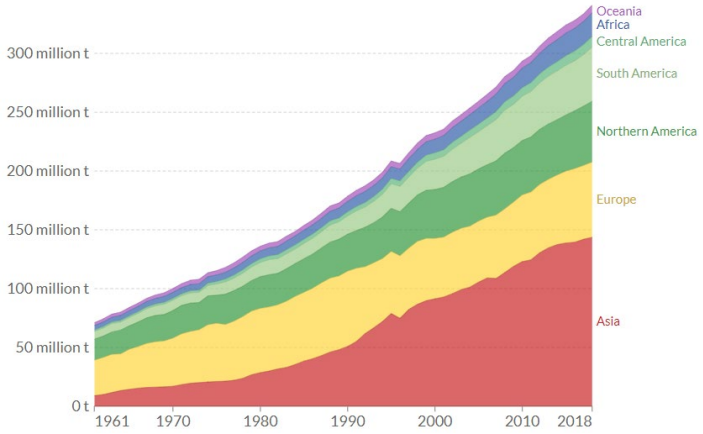
The exogenous impact of more intensive global food systems has reversed or decelerated the progress to achieve the United Nation's Sustainable Development Goals (SDG) which are aiming for a more sustainable future (FAO, 2018). The world is going to find it increasingly difficult to meet the following challenges (United Nations, 2022):

- Providing food security across all agricultural products and eradicating hunger (SDG #1 & SDG #2) has become more difficult than before. This is due to rising food insecurities related to Covid 19, the Russia-Ukraine war and other global uncertainties. Disruptions in supply chains have left millions of children malnourished and pushed countries to impose trade sanctions.
- Protecting and preserving natural resources by instilling a sustainable approach to enhance productivity (SDG #6, SDG #7 & SDG #12).
- Adapting to different climate change mitigation strategies (SDG #13) under global uncertainties due to increased heatwaves, droughts and floods.

Recent disruptions like political wars and global pandemics have put additional strain on global food systems. While global food insecurity, a collective action problem, calls for a co-operative solution, this review focuses on the meat industry in isolation.

The Food and Agriculture Organisation (FAO) forecast that world meat production in 2021 would reach 352.7 million tonnes, a 4.2 per cent rise from 2020, with the highest growth rate since 1997 (Food and Agriculture Organization, 2017) (Figure 1). This rate will need to increase since the global population is estimated to reach 10 billion by 2050 and the demand for animal-based food is expected to grow subsequently by 70 per cent (Choudhury et al., 2020; Godfray, 2019). Production systems must consider the changing patterns in protein consumption due to rising income in low- and middle-income countries along with population growth as they tend to favour increasing meat consumption. Bennetts's law of agricultural economics and development economics stating that the global demand for animal-based foods is likely to increase more rapidly than human population growth supports the behavioural change. These external influences not only impact trade and production but also apply a significant pressure on natural resources (Food and Agriculture Organization, 2017).

Figure 1. Global meat production, 1961 to 2018



Source: (Ritchie, Roser & Rosado, 2020a)

The potential of cultured meat as an animal protein alternative for the global meat production system based on its potential positive effects on carbon footprint and land use reduction is shown in Figure 2 (GFI, 2021). This is mathematically derived data; its real impact can only be calculated once the supply chains are established and a significant consumer base modifies their dietary preferences. The importance of reliance on a renewable source of energy cannot be ignored and the definition of 'ambitious benchmarks' is rather unclear. Both issues are beyond the scope of this review.

The first company in the realm of cultured meat started in 2011, and the confidence in the science has brought about 107 new companies that are committed towards making this a feasible reality, as of 2021 (GFI, 2021) (see Figure 3). Many are diversifying or extending their conventional meat operations while some are also trying to carve out a niche for themselves by targeting specific meats and their market.

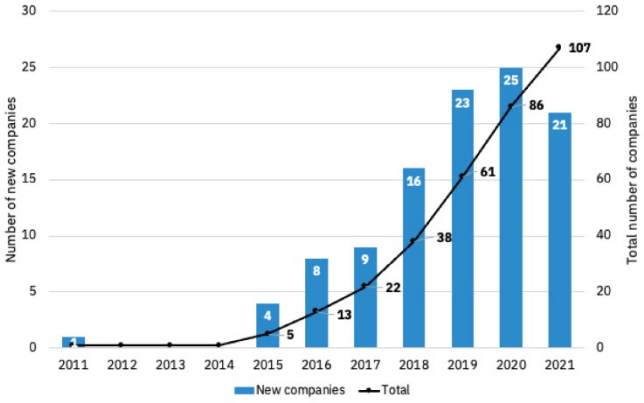
Investment is increasing and companies around the world are trying to innovate to establish an advantage in the global market, but the growing anticipation is coupled with a high degree of uncertainty. This systematic literature review will contribute as it organises the scientific research and parallel studies on consumer acceptance in different parts of the world. This methodology is aimed at analysing the available data and categorising them from different economic perspectives.

Figure 2. Environmental impact comparison between cultivated meat produced with renewable energy and ambitious benchmarks for conventional meat

	Cultivated meat compared to conventional chicken	Cultivated meat compared to conventional pork	Cultivated meat compared to a conventional beef
Carbon footprint	17% reduction	52% reduction	Up to 92% reduction
Land use	63% reduction	72% reduction	Up to 95% reduction

Source: (GFI, 2021)

Figure 3. Number of companies in the cultured meat sector



Source: (GFI, 2021)

SLR Process

While initially developed as a tool for structuring research in the field of medicine, systematic literature reviews (SLR) today provide an essential contribution to knowledge advancement in many other fields of sciences (Durach, Kembro & Wieland, 2017). The guidelines outlined by Durach, Kembro & Wieland (2017) is adapted to suit idiosyncrasies of different fields. It defines the approach of this review by influencing retrieval, selection, and synthesis of relevant literature in the following six steps: defining the research question, determining the required characteristics of primary studies, retrieving a sample, pertinently selecting and synthesising the literature and reporting the results.

The research question posed is: Does cultured meat have the potential to be a preferred animal sourced protein in the market given signs of rising demand for cultured meat? Thus, understanding the role of different value chains and their contributions in different economies needs to be approached through the lens of consumer perspective. This is achieved through inclusion of scientific research analysis and empirical evidence on consumer preferences. *Environmental and Resource Economics, Frontiers in Sustainable Food Systems, Cleaner and Responsible Consumption, American Society of Animal Sciences, Meat Science, Appetite* and *Journal of Integrative Agriculture* are some of the relevant journals used in this analysis.

Key words and phrases utilised to retrieve the preliminary sample of available literature included, 'cultured meat', 'sustainability', 'consumer preferences', 'perception', 'alternative protein', 'environment', 'developing country', 'regulations' and 'growth potential'.

Study in this area is dominated around developmental science to attain scale of production and the quest to synthesize a product imitating natural meat. Another set of studies revolve around consumer preferences and perceptions of diets. Most of the relevant literature has been over the past 10 to 15 years. The Food and Agriculture Organization, government organizations and research institutes have contributed through white papers, reports, and regulatory efforts along with efforts of researchers with focused group studies.

The following review is organized to develop a reasonable understanding of the subject which helps in adding context to the analysis. The negative externalities of the current business-as-usual agriculture system have provided a compelling argument since the inception of cultured meat research. While there is no consumer behaviour analysis available, the literature focusses on consumer perceptions of products. These studies are then utilized to review the product from different economic backgrounds: a developing country (India); a developed country (Australia); and a country close to launching the product (Singapore).

Negative Externalities of the Conventional System

The entire food supply chain creates approximately 13.7 billion tonnes of carbon dioxide which is equivalent to 26 per cent of all anthropogenic greenhouse gas (GHG) emissions. It also contributes a significant amount of global terrestrial acidification and eutrophication, approximately 32 per cent and 78 per cent, respectively. Furthermore, the farm stage in the food chain dominates at 61 per cent of food's GHG emissions, 79 per cent of acidification and 95 per cent of eutrophication. The entire agricultural system is highly resource intensive causing substantial damage to the environment as well as the arable land base (Poore & Nemecek 2018).

Industrialisation of farming activities has been the general approach by conventional meat producers working to satisfy constantly increasing global demand with limited farmland availability. Unfortunately, this change has had an adverse impact on global health leading to negative externalities on the environment, particularly on water and land resources. Assuming the conventional system of agriculture continues to feed the growing population of the world with no change in diet, the associated social costs are projected to exceed $US 1.7 trillion per year by 2030 (FAO et al., 2022).

As of 2016, agriculture and forestry land use contributed 18.4 per cent of total global GHG emissions, out of which livestock and manure shared 5.8 per cent of the emissions. Considering just the emissions from livestock, ruminants produce methane gas, which is 30 times more harmful than CO2 (Princeton University, 2014), as a by-product of their digestive activities sharing 39 per cent of total livestock emissions. The higher digestive capacity of cattle and sheep leaves a larger carbon footprint (Ritchie, Roser & Rosado, 2020a) while the aggregate production quantity of chicken can also have a significant impact.
While cattle farming can represent as much as 65 per cent of total livestock emissions, through the meat industry chain there are multiple other activities that contribute to these emissions. Manure storage and feed production and processing activities contribute up to at 10 and 45 per cent respectively, and the remainder can be attributed to emissions through transportation and any value-added processing of the animals (FAO, 2013).

The current meat production system is one of the most supported commodities in the global market through policies directed towards its productivity, protection of farmer income and food security. This system is also layered with multiple parameters that have a significant impact on consumer perception. Animal welfare along with public health concerns are leading the reasons amongst people

under 25 years of age. The idea of cultured meat is seen as a means to control this intensive livestock production industry (WEF, 2019).

FAO believes that switching to a plant-based dietary pattern, which includes a possible involvement of a cultured meat supply chain, would reduce the social costs of GHG emissions by 41-74 per cent by 2030 (FAO et al., 2022).

Animal Welfare and Zoonotic Disease

Two major factors that promote research into the production of cultured meat are animal wellbeing and zoonotic diseases. Though the presence of laws to recognise animal suffering presents a guideline, it is often up for debate on the capacity of animals to withstand pain. Hence, animals are often inflicted with pain due to the ambiguity amongst humanity, this act of suffering and moral indefensibility is recognized by the advocates of cultured meat (The Humane Society of the United States, 2009).

Many animal activists have spoken against the conditions in which animals are kept on farms before being harvested, and that the idea of cultured meat being a "victim-less" meat bypasses these moral ramifications (Bhat & Fayaz, 2010). It also possesses the potential to not only reduce animal suffering in livestock farms across the world but also eventually satisfy epicurean and nutritional requirements of the meat-eating population (Hopkins & Dacey, 2008).

Another concern lies with regard to zoonotic diseases that transmit from livestock and risk public health on a global scale. The impact of the Covid-19 pandemic is a case study of the detrimental effects of zoonotic disease on public wellbeing and a country's economic strength. Some 75 per cent of all infectious diseases are of zoonotic origin and, though associated with raw meat consumption, their risk cannot be overstated (Espinosa, Tago & Treich, 2020; Karesh et al., 2012). The emphasis on a safer alternate protein is seen by some as a necessity to prevent the emergence of new infectious and resistant diseases and thus only mitigate the future uncertainty of pandemics (Balasubramanian et al., 2021).

To summarise the demand for alternate sources of protein, they can be distilled to three major reasons: first, the rising population which puts strain on the conventional meat production system and the capacity of arable land; second, the growing environmental impact of livestock management and lastly, the strain on production facilities sparking societal worries about animal welfare as well as its consequent impact on public health (Post, 2012).

Nomenclature and Its Background

"Fifty years hence, we shall escape the absurdity of growing a whole chicken in order to eat the breast or wing, by growing these parts separately under a suitable medium" (Churchill, 1932).

Modern food markets host multiple alternate sources of proteins which have garnered a lot of positivity amongst vegetarians trying to balance their nutrient intake. It has been rather challenging to find a substitute to meat itself due to lack of efficiency in achievements on two fundamental fronts, mimicry, and efficiency. Mimicry is associated with consumer acceptance whereas efficiency is paramount to establish an industrial process of production at scale (Post, 2012). Cultured meat is a solution striving to mimic the profiles of meat grown conventionally in terms of physical attributes like taste, smell, texture, and appearance, simultaneously also making efforts to achieve the scale at which it can be affordable, accessible, and profitable (Verbeke et al., 2010).

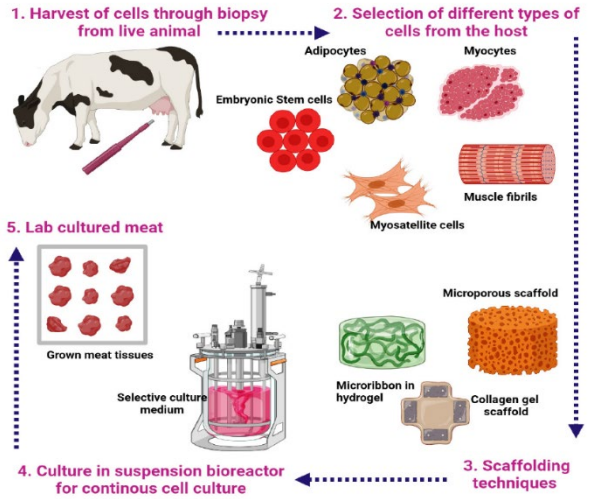
Over the years since Winston Churchill shared his thoughts, the technology has progressed and is able to utilise stem cells from animals and produce bio-artificial muscles. Initially serving as a research tool and for possible medical implants, overtime it has been engineered to explore possible cultivation of edible sources of protein (Dennis & Kosnik, 2000). Its representation has been under a constant flux with multiple nomenclature associations to find the best representation. This deliberation is a result of striving to achieve maximum appeal, descriptiveness, and differentiation from conventional meats (Ong et al., 2020). Multiple studies have been conducted by The Good Food Institute (GFI) testing different names and their impact on product acceptance. Their results show that "slaughter-free" performed best under all the above-mentioned criteria, whereas "cultured", "craft" and "clean" also were preferred under a differentiated combination preference (Szejda, 2018).

Other prefixes to meat include "in-vitro" (Langelaan et al., 2010), "cell-based", "lab-grown" and "cultivated" which are often used in the literature to describe "cultured" meat (Post, 2012). Deriving the right nomenclature involves a mix of consumer acceptance and regulatory norms which encompass other animal products in its category.

The Manufacturing Process for Cultured Meat

A short summary of the production process will help review challenges faced in the process and get a better understanding of consumer acceptance. A representation of the scaffolding process of production of cultured meats is shown in Figure 4 (Balasubramanian et al., 2021). The analysis entails limited nature of major components in this process that impact consumer acceptance and the production efficiency.

Figure 4. Scaffolding process



Source: (Balasubramanian et al., 2021)

The process begins with harvesting stem cells from a farm animal owing to their ability to self-renew while retaining the potential to differentiate into one or more tissue lineages. This development is seeded in the stem-cell research which complements the development of the cultured meat sector. Cells are then exposed to a culture medium which determines the resource efficiency, scalability, and cost effectiveness of the product. As the cells are incubated in the medium, their growth is extended using bioreactors where it develops into organoid or tissue production while maintaining the cells growth in a proliferative state (Post et al., 2020).

Critical factors of this chain limit the accessibility of the final product. To begin with, the cell culture media used for incubation challenges the sustainability of the process. Universally the scaffolding uses foetal bovine serum which supplements a mix of proteins and metabolites that create an ideal environment for cell growth. However, it is harvested from pregnant cows during slaughter posing ethical challenges to its consumption (Jochems et al., 2002) and leaves the process susceptible to contamination risks. Lack of clarity of its complete composition add to the ambiguity and the pursuit of an ideal replacement can only be achieved, currently, at high cost (Post et al., 2020).

Consumer Acceptance

"… to a far greater extent than most of us realise, culture writes the menu. And culture does not take kindly to substitutions" (Roach, 2013).

In a food market saturated with choices and products that cater to every consumer tailored diet, demand pull becomes an essential external driver determining the course of food production systems (Klink-Lehmann et al., 2022). Analysis of consumer behaviour is largely in a predictive and anticipatory state due to the infancy of this product category's development cycle and lack of accessibility. Nevertheless, studies with focus groups have been able to extrapolate the path by laying down consumer opinions through data collection. For this review, the factors have been scrutinised based on previous research papers and categorised to analyse how they would catalyse or inhibit the progress of the value chain.

Animal welfare and environmental benefits

The most commonly perceived benefit across consumer studies has been the ability to avoid animal slaughter (Bryant & Barnett, 2018). Adoption of this new technology has the potential to reduce animal cruelty, and its acceptance will have a direct impact on the demand of the conventional meat and over time can lead to fewer slaughters. Ethical concerns will favour the technology if the development does not lead to a perception of it 'tampering with nature' (Verbeke et al., 2015). The regulations set around process and nomenclature would be responsible for mitigating a negative consumer perception.

Lynch & Pierrehumbert (2019) and GFI (2021) support reduction in environmental impact with consumers transitioning towards a cultured meat diet. Since the supply chain is still in a very early stage, the true impact on the environment cannot be known. Consumer studies have contributed insights by acknowledging the invention and increasing consumer awareness which contribute towards developing an effective marketing strategy in developing countries (Bryant et al., 2019).

Religion

Cultured meat aims to target the global population and a factor that determines many food choices is religious belief systems. Especially with the meat industry, the consumption of meat tends to be restrictive depending on the religion of the consumer. A potential cultural debate around the acceptance of lab-grown meat and its market potential proposes a dilemma amongst the 1.8 billion Muslim, 1.1 billion Hindu, half a billion Buddhist and over 10 million Jewish diets (Bryant, 2020).

The majority of rabbis have a consensus on cultured meat being kosher with a critical caution on the origin of the cell being from a kosher-slaughtered animal (Kenigsberg & Zivotofsky, 2020). Similar argument on the origin on the cells from a halal-slaughtered animal is rather strongly emphasised in Islam along with a necessary absence of blood or animal-based serum (Hamdan et al., 2018). As far as pig meat is concerned, it remains disapproved as per scriptures and hence reciprocates in the survey

with the least percentage of people showing any inclination to try it (Bryant et al., 2019). Buddhist monks refrain from eating meat altogether and there is no religious text on any permissibility with regards to the prospect of cultured meats. Nevertheless, the survey by Bryant et al. (2019) had a positive response with more than 60 per cent finding cultured meats appealing.

Hindus, as a religious group, showed most willingness to eat cultured (Bryant et al., 2019). Their religious ideology is based on the concept of *ahimsa*, which translates to non-violence, and the majority of its followers are vegetarians. The introduction of cultured meats poses an interesting choice for Hindus as they can consume meat produced without violence. It is promising since the scriptures don't explicitly mention the compulsion to follow vegetarianism (Soni Satpathy-Singh, 2014) however, since cows are considered holy, the acceptance of beef in any form is expected to be restrictive. The presence of ambiguity in Hinduism leads to India, the country with the largest population following the religion, being a possible growing market for cultured meats.

Pricing

Price is an important factor for consumers. According to a survey by Verbeke et al. (2015), 42 per cent of participants refrained from paying a premium price for cultured meat. Even after discussing the additional environmental benefits, the percentage decreased insignificantly. In fact, a significant increase in acceptability at a lower price range is coupled with higher market share amongst consumers. Due to the uncertainty of the real price in the market, many meat consumers envisioned personal benefits and were open to exploring possibilities; but they would only consider a partial shift from their traditional meat diet (Verbeke et al., 2015).

The 'Yuck Factor'

Neophobia is a major issue pertaining to consumer acceptability of cultured food. The reticence towards new food often leads to a sense of disgust stemming from lack of knowledge or the novel nature of the product. This 'yuck factor' is a typical initial reaction (Pluhar, 2009) as more and more technological interventions in creating food products generate fear (Verbeke et al., 2015). Since preceding consumer beliefs play a more important role in willingness to purchase (de Oliveira Padilha et al., 2022), it is essential to lower the food neophobia with respect to cultured meats with better familiarity of the product (Bryant et al., 2019).

'Not in my backyard'

The analysis of multiple factors that impact consumer acceptance can be categorised mainly into personal and social benefits. Across case studies, the reasons to change to cultured meat depend on the economic environment of the country and are eventually at every individual's discretion. As the Roach (2013) quote above also suggests, culture is an important factor to consider when any change in food systems is mooted, and substitutions are often questioned initially. The food system should not expect an easy transition nor immediate revenue, it will require a careful understanding of the market and, thereby, its pulse. One cannot prefer targeting social benefits in isolation while expecting a comprehensive response, owing to the presence of uncertainty in personal benefits consumers can resort to a 'Not in my back yard' attitude (Verbeke et al., 2015). This is even more a possibility due to an imbalance in principle-led theories over practice and real-life behaviour led data.

Media and regulation

Numerous nomenclatures for this invention are not just a result of ambiguity and curiosity amongst consumers; rather, it also is a way to mitigate any consumer pejorative perceptions stemming from

their concerns. Intervention from government institutions has been pivotal to streamlining the approach businesses should take with terminologies. The question garnered attention with the growing popularity of the term 'plant-based meat' which is derived from 100 per cent plant-based protein, diluting the definition of 'meat'. The central issue discussed in this section is categorisation of cultured meat and primary steps being taken in the United States and in Europe (Post et al., 2020).

The Bryant and Barnett (2018) study demonstrates that the associations made by consumers with respect to cultured meat determines the consumer behaviour and their likelihood to try. Marcu et al. (2015) uses social representation theory to bridge the connection between lack of familiarity with cultured meat causing consumers to draw parallels from familiar concepts which, in this case, may have been publicly criticised. Hence, cultured meat is often rejected due to a consumer perception of it being unnatural (Laestadius & Caldwell, 2015; Verbeke et al., 2015). According to the Good Food Institute (2021), 'safe' and 'clean' generated the greatest consumer acceptance, which was also confirmed in another study by (Bryant & Barnett, 2019). Arguably, 'clean meat' generated more support as it benefited from the already established "clean energy" terminology in the media (Szejda, 2018).

The lack of uniformity in addressing a product has called for regulatory appeal and multiple efforts have been made to define cultured meat in a globally accepted way. In Europe, the product falls under Novel Foods Regulation which will need authorisation from the European Food Safety Authority (EFSA) guiding consumers towards the safety of its consumption and adequate labelling to prevent nutritional misleading. In Table 1 the definition of cultured meat as per EFSA and the attributes required to qualify for consumer sales is described (European Food Saferty Authority, 2020). Post the assessment, the authorisation mandates a risk assessment stage for sales in the European Union ensuring the companies do not overlook consumption safety (Treich, 2021).

The United States brings a lot more clarity in the regulatory framework compared to that of the European Union. Two bodies work together to organise the complete supply chain of cultured meats. The Department of Agriculture (USDA) looks after the post-harvest process including processing and labelling, and the Food and Drug Administration (FDA) regulate the pre-harvest production process and materials (USDA, 2019). Details regarding labelling are yet to be determined, hence the correct nomenclature is still being looked at from multiple perspectives. However, it will not be subjected to the norms of genetically engineered food which are drafted by USDA until it is classified or until a new list of rules are drafted (Faustman et al., 2020). This also leaves the door open to cultured meat being potentially categorised as craft meat with specifically designed nutritional characteristics which is only at the discussion stage.

In Table 2 the standards laid out by FDA to categorise ingredients as "safe and suitable" are identified and it is not yet equipped to efficiently describe cultured meat (Ong et al., 2020). FDA regards ingredients as "generally recognised as safe" (GRAS) which have been adequately shown as safe for consumption by qualified experts. This includes salt, pepper and many cultured products made using bacteria and yeast (U.S. Food and Drug Administration, 2019). It currently renders the same logic onto cultured meat however, the growth factor and other smaller molecules used in the process are not commonly used in food and hence cannot be classified as GRAS (Thorrez & Vandenburgh, 2019).

The efficacy of the regulatory framework is slowly achieving clarity as the parallels of scientific innovations are advancing. This translates to general trust amongst consumers in accepting new technology being one of the determinants (Hopkins & Dacey, 2008). Public familiarity is an essential concept and hence multiple countries are striving to establish more and more clarity to define cultured meats.

Table 1. Safety assessment as per European Food Safety Authority

Identity	Foods consisting of, isolated from or produced from cell culture or tissue ♦ Biological source (International codes of nomenclature) ♦ Organ and tissue or part of the organism ♦ Information on the identity of cells ♦ Type of culture ♦ Stem cells, laboratory, culture collection ♦ Cell or tissue substrate used as a novel food
Characterisation	Identities and quantities of impurities, by-products or residues, antimicrobial residues ♦ Nutritionally relevant constituents ♦ Biological hazards: BSE/TSE, viruses (source, zoonotic), microbiological contaminants ♦ Type and spectrum of target analytes depending on sources and production process
Production Process	Detailed description including: ♦ Treatment, modification, immortalisation of cells ♦ Raw materials, starting substances, medium/ substrate, growth factors/hormones, culture conditions, antimicrobials, hygiene measures, description of the equipment Generic issues related to manufacturing processes using cultured cells: ♦ Potential by-products, impurities, contamination, stability of cells, consistency of the production process ♦ Operational limits and key parameters of the production process
Nutritional Information	♦ Role of the NF in the diet (based on the intended uses) ♦ Comparative approach with conventional meat ♦ Quality and quantity of macro & micronutrients
Allergenicity	♦ Basis: comprehensive compositional data, ♦ Potential use of «omics» tools (genomics, transcriptomics, proteomics)

Source: (European Food Safety Authority, 2020)

Table 2. Standards for claims by FDA

"Edible"	"Clean"	"Sustainable"	"Animal-free"
✓ (FDA) Food needs to have ✓ Nutritional value ✓ Approved additives ✓ Generally recognized as safe (GRAS) ✓ Maximum residue limit (MRL) **Further action** ✓ Cell culture additives are unapproved, require petition for approval ✓ Need for regulatory framework for cultured cells as food	(FDA) Health claims need to avoid vague claims and use specific claims (FDA Food Labelling Guide) Guidelines for claims: ✓ Healthy ✓ No antibiotics ✓ No hormones ✓ Low fat ✓ Low cholesterol With standards to meet before permitted to use claim **Further action** ✓ Set standards for level of pathogens in meat	(FTC) Greenwashing is prohibited (FTC Green Guide) ✓ General claims not permitted (e.g. "green") ✓ Specific claims encouraged ("made with recycled materials") ✓ Supported with reliable scientific evidence ✓ Life cycle analysis needs to be done following ISO	Early-phase prototypes ✓ Should not claim to be animal-free Commercialised product ✓ Cells need to be able to expand without regular cell harvests ✓ Cell culture does not require animal-derived components **Further action** ✓ Need for certification for standards of animal-free media ✓ Need for international animal welfare certification

Source: (Ong et al., 2020)

It is crucial to destigmatise the subject early on into the product lifecycle for the entire supply chain to create value post launch. Apart from that it will be a marker for safety and potential toxicity for the market and on the other hand, strict regulations can generate a potential delay in beneficial innovations (Treich, 2021). Furthermore, once launched, regulations could create imbalance in market power as firms compete to capitalise on the market, ultimately proving the overarching goal of eventual affordability to be counterproductive.

To summarise, the SLR primarily highlights the major aspects influencing consumer acceptance of the product while it strives to streamline its production. Beginning from the process and its ingredients to the psychological impact on consumers that leads to different acceptance patterns, the review condenses important talking points of the past decade. Issues on a global level that concern people like the animal welfare, zoonotic diseases and externalities caused by the current agriculture system play an important role as substitutes give people to consider alternate protein options. On an individual level, determining factors like religion, pricing and neophobia are relevant to the overall acceptability of the product in the market.

Case Studies of Progress

Owing to the infancy of the sector and since only a very minor segment of the market has been able to make cultured meat commercially viable; it is interesting to look at the potential work done in a developing country, India, and a developed country, Australia. While India potentially could be a large market, Australia is trying to adapt its established conventional meat production economy for a sustainable future. A brief look at the value chain established in Singapore will help put all the factors above into perspective and contribute to future possibilities in academia and world food systems.

Singapore

On 2nd December 2020, the Singapore Food Agency (SFA) approved Eat Just Inc. to produce and sell cultured chicken meat in Singapore (Woodyatt & Weiner-Bronner, 2022) signalling progress towards the commercial viability of cultured meat. While the production facilities are established in Northern California, the permission to produce in Singapore sets up the opportunity for better access around the world.

The California start-up is known for other alternative protein products made from plant-based sources and plans to take over Asia with other alternatives as well. The product is being branded under 'Good Meat' by Eat Just which will harness partnerships with local manufacturers (Shu, 2020). This strategy used by Eat Just to distinguish cultured meat from other products of its own can be seen as creating space in the market demand that does not coincide with plant-based protein products.

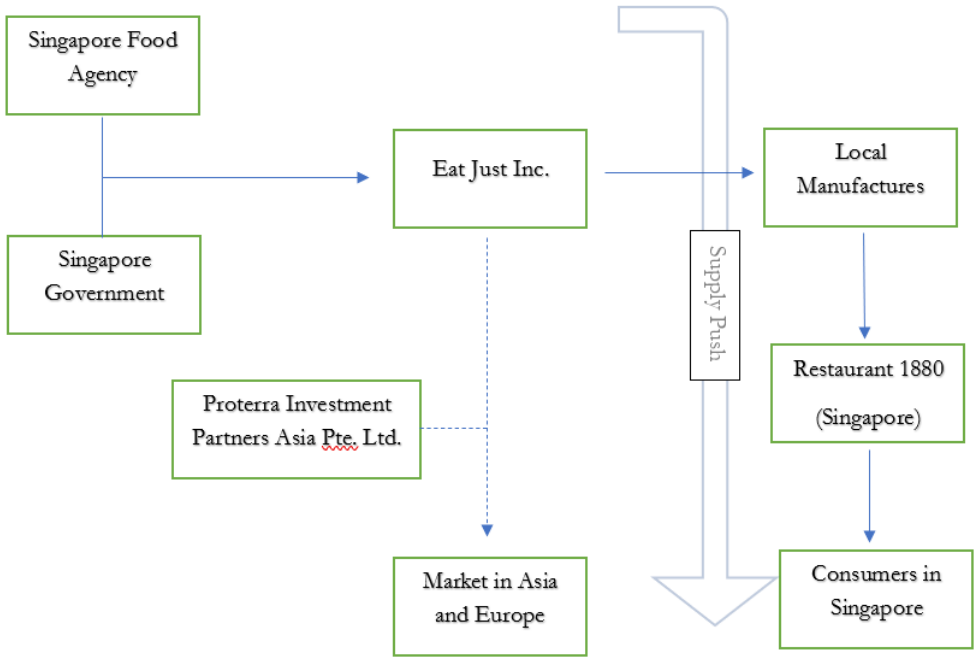
Currently produced in large bioreactors, Eat Just have claimed in their company statement that they refrain from using any antibiotics. SFA is the first regulatory body to achieve a structured review that tests and confirms the product to be safe and nutritious for human consumption. A distinguished panel with expertise in medicine, toxicology, allergenicity, cell biology and food safety from Singapore and the United States carried out the tests and reviewed the product (News Desk, 2020). The SFA guideline of 2022 lists requirements for the safety assessment of novel foods and novel ingredients which can be accessed by other institutions for reference and framework (Singapore Food Agency, 2022).

The Singapore government is focused on producing 30 per cent of their food supply locally by 2030 which is spearheaded by SFA since about 90 per cent of their food is imported (Shu, 2020). Hence, plans for further expansion for Eat Just are rooted in strategic partnerships with well-established local

manufactures in Singapore and the government. The local manufacturers will carry the production of cultured chicken cells and eventually synthesize the final product. This collaboration will enable the central links in the supply chain before the product reaches restaurants. Eventually Eat Just will build and operate from a production facility with the help of an investment consortium in Singapore to reach a wider audience in Asia (News Desk, 2020).

According to Josh Tetrick, CEO of Eat Just, complete production takes 14 days compared to a 45-day process of conventional farming. He places the product next to premium chicken and is currently priced at SDG $23 at the restaurant 1880 in Singapore. Further on, Tetrick focuses on scaling the production up where the product can be made profitable at the price set, inferring the company is not profitable at the current price point (Scipioni, 2020). Consumer reactions and its success have not been investigated and presents scope for primary data collection and analysis. With upscaling and a potential new production facility by 2023, the company aims at lowering the cost of production to that of any other conventional meat by 2030 (Ong, 2022).

Figure 1. Existing value chain representation of cultured meat in the Singapore food market



Source: McCormick (2021)

Rapid growth has garnered some criticism from academics regarding the technical aspects of scaling up ethically. Tetrick confirms the use of foetal bovine serum at trace amounts in the nuggets produced by Eat Just (McCormick, 2021) adding to lack of faith in Eat Just Inc.'s approach.

India

On track to become the world's most populated and largest economy, India's food consumption patterns are expected to have a significant impact on the global food markets and environment, especially in the meat sector where the rising economic power of the population is slowly drifting towards increase in the demand of meat-based protein (Arora et al., 2020). Subsequently, the pressure on the mainstream supply chain and its negative externalities needs careful consideration

along with mitigating any growing nutrition security issues in the country. This has created space for exploration and a big market segment for cultured meats to target and be presented as a viable solution.

The primary aim, however, has been to address the nutrition security of meat-derived protein as it contributes 35 per cent of the total protein requirement in India (Rahman et al., 2021). Post-Independence, India went through challenges with regard to putting food on the plates of its growing population. Ridden with famines and droughts, the primary objective of the Green Revolution (GR) was to address food insecurity and increase accessibility. This was indeed a breakthrough to achieve caloric sufficiency and cost efficiency. However, the production of other nutrient-rich food crops such as coarse cereals and pulses were crowded out from their traditional production environment (Pingali et al., 2017). Over the years, and in accordance with Bennet's law, rising income has shifted the focus from staple crops to a more diversified and higher-quality diet, that includes vegetables, meats, and fish-based protein (Pingali, 2007). Cultured meat possesses the capability of addressing the micronutrient malnutrition due to the lacking dietary quality calling for a re-assessment of the country's food policy (Pingali et al., 2017).

A step in the direction of progressive food policy for nutrition security is to discuss the establishment of regulations for cultured meat. GFI India details the prospect and the status of regulation in the country with recommendations to give momentum to the movement. Upstream and downstream chains could be effectively managed by established relevant authorities (Table 3) with certifications and guidelines prior to achieving production feasibility (Kamalapuram et al., 2021).

Current value chain stakeholders in India are authorities that are working on bringing efficiency in specific avenues. A competitive technological landscape, robust market environment and the start-up ecosystem are offering significant opportunities for growth and reformation. Collaborative efforts between GFI India and the Institute of Chemical Technology Mumbai have already secured permission to open a designated research centre focused on cellular agriculture (Neo, 2019). The Government of India, too, has recognised cultured meat as a sustainable and scalable approach in the alternative meat protein category further adding momentum to the movement to establish regulations (Kamalapuram et al., 2021). Educational institutes in India are taking keen interest in developing the research for better production environments as well. Table 4 (compiled by Kamalapuram et al., 2021) shows the various value chain entry points in the Indian market in both the upstream production phase and downstream collateral development.

The Food Safety and Standards Authority of India (FSSAI) released a press note early in 2017 categorising cultured meat as novel foods, subject to labelling and clearance under its authority. It is published in a comprehensive form for companies or manufacturers interested in applying for processing or selling of cultured meat. FSSAI also emphasised labelling of meat produced synthetically as "cultured" as per the regulations published in 2018 which may have been guided by the SFA. Arguments to consider a subsidised tax bracket are also proposed to facilitate production under "Make in India" and "Start-up India" initiatives by the Government of India (Dhanuka & Bhattacharjee, 2022).

The final hurdle can be deemed to be the consumer acceptance of products in India, although surveys show an optimistic picture and concur with the potential. In a survey by Bryant et al. (2019), India proves to be a market where the purchase of clean meat is likely to be high. Consumers who are politically liberal, more informed and within the higher income bracket are likely to purchase clean meat. Indians also showed lower food neophobia and higher meat attachment which can be predictive of better purchase intent.

Table 3. Relevant authorities for cultured meat supply chain in India

	Certification/Organisation/Authority	Website
Quality assurance	Hazard Analysis Critical Control Point (HACCP) by the National Centre for HAACP	https://www.haccpindia.org/ accessed on 15 September 2021
	International Organisation for Standardisation (ISO:9000)	https://www.iso.org/home.html accessed on 15 September 2021
	General Society of Surveillance (SGS) India	https://www.sgsgroup.in/ accessed on 15 September 2021
	Good Manufacturing Practices (GMP) India	https://fssai.gov.in/cms/hygiene-requirements.php accessed on 15 September 2021
	Good Hygienic Practices (GHP) India	https://fssai.gov.in/cms/hygiene-requirements.php accessed on 15 September 2021
	Export Inspection Council of India (EIC)	http://eicindia.gov.in/ accessed on 15 September 2021
Product processing	Prevention of Cruelty to Animals Act 1960	http://www.awbi.in/policy_acts_rules.html accessed on 15 September 2021
	Bureau of Indian Standards (BIS) 2007	https://bis.gov.in/ accessed on 15 September 2021
	The Food Safety and Standards Act 2006 (FSS Act)	https://www.fssai.gov.in/cms/food-safety-and-standards-act-2006.php accessed on 15 September 2021
Authorities	Agricultural and Processed Food Products Export Development Authority (APEDA)	https://apeda.gov.in/apedawebsite/ accessed on 15 September 2021
	Food Safety and Standards Authority of India (FSSAI)	https://www.fssai.gov.in/ accessed on 15 September 2021
	Department of Animal Husbandry and Dairying	http://dahd.nic.in/ accessed on 15 September 2021
	Ministry of Agriculture and Farmer's Welfare	http://dare.nic.in/ accessed on 15 September 2021
	Ministry of Food Processing Industries	https://mofpi.nic.in/ accessed on 15 September 2021
	Marine Products Export Development Authority (MPEDA)	https://mpeda.gov.in/ accessed on 15 September 2021

Source: (Kamalapuram, Handral & Choudhury 2021)

Multicultural audience with omnivores, flexitarians and largely familiar millennials have a very optimistic approach to trying cultured meats. It is also a secular country and the presence of 80 per cent of population following Hinduism (Arora et al., 2020) also can work in favour of easier acceptability on the grounds of religious belief systems. Indian consumer attitudes towards the prospect of cultured meat are outlined in Figure 6 (Kamalapuram et al., 2021).

Australia

With the backdrop of recent elections in Australia which favoured the agenda to tackle climate change, cultured meat proposes to be a relevant field of discussion. Naturally a lot of focus has been put on the greenhouse gas emissions in the Australian context as it is leaving a very high carbon footprint per capita in the world at 17 tonnes, as of 2020 (Figure 7) (Ritchie et al., 2020a). Livestock emissions in Australia contribute 70 per cent of all agricultural emissions which are 11 per cent of all total GHG emissions including energy and transport sector (Curnow, 2021).

Table 4. Value chain entry points in India

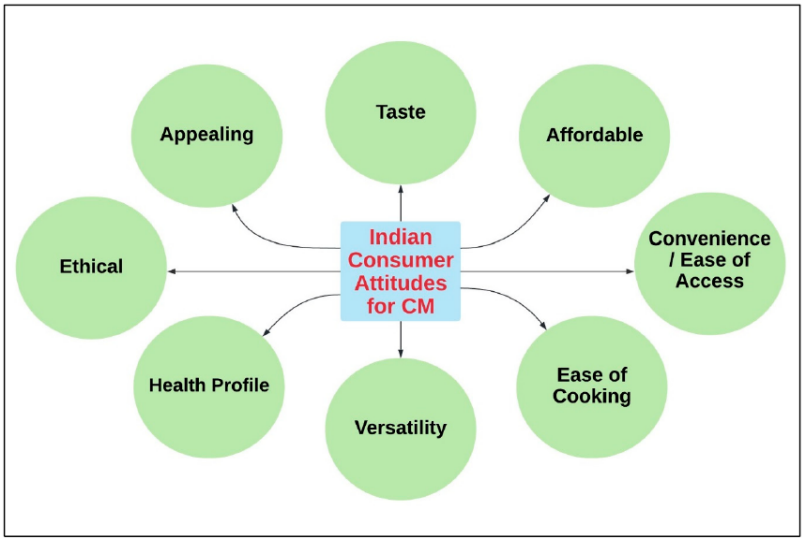
S. No	Value-Chain Entry Point	Prospective Strategies/Growth Avenues	Stakeholders Involved
Upstream/Production			
01	Cell Line Development	• Species-specific/native cell line isolation and biobanking • Carbon-footprint-free cell line immortalisation and maintenance techniques • Automated cell screening systems • Genetic engineering for unique cell line variants	DBT India; AIC-CCMB; ICT Mumbai; CECA; NRC Meat; GFI India; HSI India; Clear Meat; IIT Guwahati
02	Cell Culture Media and Ingredients	• Animal-free origin ingredients • Growth factor mimetics • Novel molecule screening platforms • Fermentation additive products • Micro or nanofluidic cell culture systems	DBT India; AIC-CCMB; ICT Mumbai; CECA; NRC Meat; GFI India; HSI India; Clear Meat; IIT Guwahati; RichCore Life Sciences
03	Scaffolding	• Biocompatible hydrogels, nanofibers, nanotubes • 3-D bioprinting, extrusion technologies • Photopolymerisation • Self-directed architecture	DBT India; AIC-CCMB; ICT Mumbai; CECA; NRC Meat; GFI India; HSI India; Clear Meat; IIT Guwahati; MyoWorks
04	Bioreactors/Cell Cultivation Systems	• Media recycling and filtration • Automated continuous bioreactors • Artificial intelligence (AI), machine learning (ML), and internet of things (IoT)-based sensors for the control and monitoring of the growth environment • Automation of bioprocessing units	DBT India; AIC-CCMB; ICT Mumbai; CECA; NRC Meat; GFI India; HSI India
S. No	**Value-Chain Entry Point**	**Prospective Strategies/Growth Avenues**	**Stakeholders Involved**
Downstream/Collateral			
05	Manufacturing/Production	• Facility design, construction, management, and maintenance • Co-manufacturing/co-packing units • Customised Indian CM product variants • Product branding and white label process	DBT India; ICT Mumbai; CECA; GFI India; HSI India
06	Sales and Distribution	• Indian cultural expertise • Branding strategies, marketing, and sales • Product consulting and brokerage system • Export and import market • Global expansion paradigms	DBT India; ICT Mumbai; CECA; GFI India; HSI India
07	Supply Chain Management	• Quantity and quality assurance • Packaging and distribution channels • Effective local and global sourcing	DBT India; ICT Mumbai; CECA; GFI India; HSI India
08	Regulatory and Business	• Regulatory and safety certifications • Intellectual property and patents • Business and legal consulting • Entrepreneurship and technology transfer	DBT India; AIC-CCMB; ICT Mumbai; CECA; IIT Guwahati; GFI India; HSI India; Clear Meat; BIV; Gastrotope; String Bio 19

Source: (Kamalapuram, Handral & Choudhury 2021). *Legend for Table 4*: Department of Biotechnology, India (DBT India), Atal Incubation Centre – Centre for Cellular and Molecular Biology (AIC-CCMB), Institute of Chemical technology (ICT) Mumbai, Centre of Excellence in Cellular Agriculture (CECA), national meat research centre (NRC Meat), Good Food Institute (GFI) India, Humane Society International (HIS) India, Big Idea Ventures (BIV) India, Indian Institute of Technology (IIT) Guwahati, Oil and Natural gas Corporation (ONGC).

Over time, the consumption pattern of meat in Australia has also seen a shift as non-ruminant meat gains popularity over ruminants. Chicken and pork consumption have tripled and doubled, respectively, between 1974 and 2014 while beef and lamb consumption fell by 45 per cent and 64 per cent respectively. This encouraged proponents of alternate meat to look at other sources of meat. Kangaroo meat has also been discussed in previous literature as advocates of the idea believe it to be a method to control the pest, and simultaneously consume healthier lean red meat, although, many

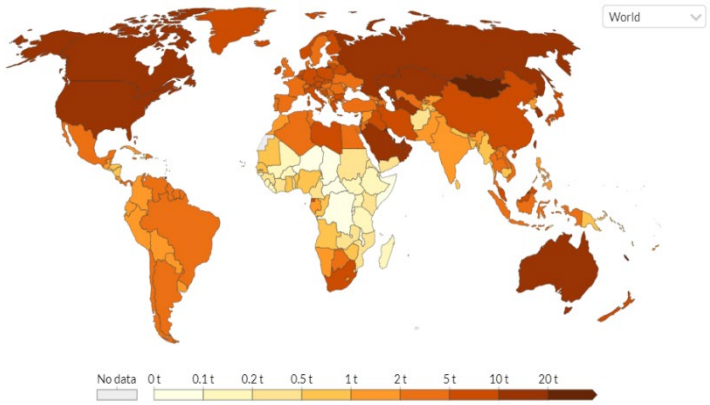
oppose the consumption of Australia's national icon (Ratnasiri & Bandara, 2017). Vow Food has developed the first cultured kangaroo meat for Australians and expects to be able to address market share for game meat through this sustainable alternative (Cherney, 2019).

Figure 6. Indian consumer attitudes for cultured meats



Source:(Kamalapuram et al., 2021)

Figure 7. Per capita CO_2 emissions, 2020



Source: (Ritchie, Roser & Rosado, 2020a)

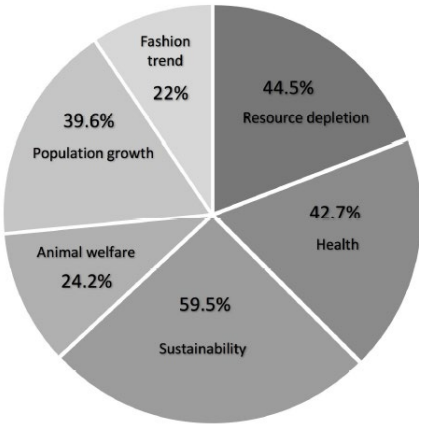
Another issue with the Australian population with regard to food is malnutrition in the form of excessive energy intake of caloric dense food and high meat consumption leading to obesity. There was a 66 per cent increase in energy intake per portion between 1995 and 2012 (AIHM, 2017) adding stress on the livestock production systems of Australia to increase supply.

Cultured meat could possibly feature as a solution that prescribes nutrient specific meals addressing the malnutrition in a developed economy as high spending power could be an exponent of affordability. Australians spend only 23.5 per cent of their total average food expenditure on a nutrient-adequate diet (Ritchie, Roser & Rosado, 2020b), indicating the ability to compensate for the high cost of cultured meats. Simultaneously, the rising demand for chicken and its negative externalities can be an area of focus to develop cultured chicken meat supply (Wiedemann et al., 2020).

Due to the infancy of the market in Australia and that a large contribution comes from conventional agriculture, businesses like Thomas Foods International have recently invested in plant-based protein research. As of 2021, there were only three companies working with cultured foods, Vow Foods being one of them and the country has also established the Alternate Protein Council in March of the same year (GFI, 2021).

With all the development on research and investment by companies, consumer studies in Australia have been collecting data to minimise risk and maximise value chain effectiveness. Over the last decade there has been a trend where 'meat-reduced' diets have been prevalent amongst the citizens (Roy Morgan Research, 2016). A consensus (Bogueva & Marinova, 2020) suggests that 72 per cent amongst the Generation Z of Australia tends to swing towards finding cultured meat unacceptable (Figure 8). The majority of Australians associate it with a feeling of disgust due to its unnaturalness leading to also believing it to be unhealthy. However, a silver lining in this study from 2020 suggests that a total 53 per cent of the population have a positive reaction. This positivity is associated with being willing to try the new product and its role in of helping with food security. It also suggests that further information regarding animal welfare and health impacts of livestock farming have the potential to sway opinions of the younger population accounting for up to 41 per cent. Studies over the next few years also detailed factors of consumer preferences (de Oliveira Padilha et al., 2022; Malek & Umberger, 2021a, 2021b).

Figure 8. Reasons for embracing meat alternatives for generation Z of Australia



Source: (Bogueva & Marinova, 2020)

Upon investigating details of diet preference amongst Australians, there was a prominence of an omnivore diet followed by a flexitarian diet that indicated a perception in willingness to reduce meat consumption. 'Flexitarian' is an ambiguous term but in the academic literature it is universally related to lowering consumption of meat and/or fish. Flexitarians are more likely to place higher importance on egoistic food choices that include health and nutrition, price, familiarity, and convenience. These egoistic factors are a more common source of motivation than ethical or social factors (Malek & Umberger, 2021a).

Consumer perception specifically towards cultured meat was associated with higher prioritisation towards eating enjoyment, safety, animal friendliness and healthiness of the product. A higher trust was levied upon Commonwealth Scientific and Industrial Research Organization (CSIRO) by the Australian consumers indicating their involvement is necessary in establishing regulation for cultured meat to increase acceptance (de Oliveira Padilha et al., 2022). Environmental impact was acknowledged as one of the main causes for this change but it was not a reason strong enough to

influence willingness to consume whereas, health motivated the most to shift diets (Malek & Umberger, 2021b).

Discussion

Challenges

Mapping the strategic fit for an industry in its very nascent stage of research can help identify the challenges in the market. While there is only a singular commercial supply chain established as yet in Singapore, the challenge is for the companies to develop an alignment between the competitive and supply chain strategies for the future. In this case the literature review on the existing value chain research will help analyse factors to determine the direction the cultured meat industry can explore to achieve its tailored strategic fit.

Cultured meat stands with high implied demand uncertainty due to the attributes of consumer satisfaction that range from nutrition security and economic affordability in India to animal welfare and egoistic factors in Australia. At the same time, efforts to increase consumer knowledge and familiarity will help bring down the overall demand uncertainly in the market, since higher education amongst the younger population led to more willingness to consumer cultured meats (Bryant & Barnett, 2018). The supply uncertainty currently is quite high due to operational challenges but looking at the life cycle position of the product, this is not atypical (Chopra & Meindl, 2016).

It is crucial for businesses to establish themselves on a coherent strategy across the supply chain. The cultured meat supply chain faces a cost-responsiveness efficient frontier and is subjected to balancing cost efficiency and responsiveness. As the companies struggle with high operational costs, the consumer perception data will help with increasing responsiveness in tailoring the product accordingly. Subsequently, with possible technological breakthroughs in future that bring down the cost of production, the industry can move along the frontier to be more efficient and responsive, building a sustainable value chain (Chopra & Meindl, 2016). Increasing consumer perception research on cultured meat will assist in minimising the implied demand uncertainty of a novel product in markets. On the other hand, the necessity to be affordable to compete with the conventional meat market poses a subject for further research in global food markets.

Opportunities

The scope of growth in this emerging industry has attracted a lot of capital investment in recent years from governments and businesses. It has contributed to research and development across the supply chain in the form of consumer perception data and technological growth in its science (Kamalapuram, Handral & Choudhury, 2021). These are indicators of cultured meat potentially becoming a commodity in the market (Post et al., 2020).

Utilising the performance measures established by Aramyan et al. (2007) for the agri-food supply chain, the opportunities for growth can be categorized to eventually have a successful supply chain. While the efficiency and responsiveness of this industry has been discussed as its challenge, data and literature point towards opportunities that can improve quality and flexibility. The cell culture medium to grow meat is an area with the largest potential to expand as its current form is a scale-limiting challenge.

Research is targeted towards achieving low environmental footprint and an ideal source of nutrients other than foetal bovine serum. Biomass from algae and certain bacteria cultures are cheap reservoirs of nutrients and contribute to a sustainable cycle of production with CO_2 capture and waste

treatment. Implications of this change will have an overall improvement in the process quality with fewer negative externalities on the environment and cost efficiency. Subsequently, the process will also be able to ethically scale the production and improve customer sales service. Though the technology has been successfully demonstrated, it remains to be tested on mammal cell cultures (Post et al., 2020). Another major factor favouring cultured meat production is reducing zoonotic diseases, and the opportunity to diversify meat culturing technology into alternative meats will help replace health compromising food systems (Balasubramanian et al., 2021).

Supporting the opportunities and challenges, investment in marketing the product correctly with the right use of terminologies as per the data collected will be able to draw attention to cultured meat. Over-complication with excessive scientific explanation might alienate the audience but utilising commercial space of restaurants and experienced suggestions of a chef will help drive the consumer perception in the right direction.

Conclusion

The emergence of cultured meat as a valuable alternate animal protein is rooted in a combined effort by all the stakeholders of the value chain. In attempts to capitalise on the market, these actors in value chains face multiple trade-offs through the decisions they make. These decisions are being supported by active research in the field of science, technology, and consumer perception to reduce risk and uncertainty.

The major trade-offs on the producer side of the chain lie between cost efficiency and responsiveness. In the race where the investment by companies is growing to put the product on shelves, the ability to justify its high price point requires further research and scientific development. Whereas, on the consumer side, the willingness to try is subject to awareness, affordability and overall palatability of the product being in direct comparison with the conventional meat industry. Regulatory firms are trying to establish approvals and guidelines for producers at the risk of creating an imbalance in the market power while also protecting food safety for the consumers (Treich, 2021).

A cohesive approach from all the stakeholders is essential to reduce externalities from the current conventional meat industry. As consumers and producers approach the product from different perspectives, there is the risk of not achieving strategic fit. This duality may slow down the progress or may even lead to a misrepresentation of intent.

Both developing and developed countries show the potential for the product to co-exist on market shelves as it caters to different preferences and diets. The product's ability to completely replace the conventional meat is questionable but it does exhibit the potential to release pressure from the conventional meat systems with a systematic approach.

Ultimately, all parts of the value chain require further research and analysis to arrive at a consensus for maximum market appreciation in developed and developing countries. While this could be a staggered and differential approach based on the target audience, the market segment has the potential to increase sustainability in global food systems.

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