Bombay Technologist

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A Review of plant-and fungi-based meat and cellular meat: an Indian perspective

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With climate change only becoming an increasingly looming threat to the survival of humanity, it is imperative that we as a species take steps to reduce our impact on the earth. One such method that is often mentioned is switching to a diet less dependent on meat. However, such advice is often met with scepticism and reluctance from conventional meat consumers. But with the rise of companies making both plant-and fungi-based meat (PBM) and cellular meat (CBM) in recent years, the process of switching to a more sustainable diet has become a lot easier. For a country like India which, despite having around 34% vegetarians, is increasingly consuming more meat, meat alternatives are a promising option. This paper shall thus analyse the development and scope of meat alternatives such as PBM and CBM, their production, manufacture, driving forces and consumer attitudes from an Indian perspective. There shall further be an attempt to analyse their nutritional values vis-a-vis conventional meat, i.e., animal-based meat (ABM) products. The effects of the rise of such alternatives on both the planet and the population as a whole shall also be detailed. In addition, the future potential and upscaling of such processes to feed whole populations shall also be addressed.

Keywords: Plant-based meat; climate change; cellular meat; meat alternatives; India; mycoprotein

1. Introduction

For millions of years, humans have consumed meat as a core part of their diets. Over the years, improvements in farming technologies, as well as the multi-fold growth of the meat industry, have worked to bring about an increase in efficiency and lowering of the cost of ABM [1]. According to the Food and Agriculture Organization (FAO) of the United Nations, by 2050, meat demands are projected to rise to 455 M metric tons [2]. The demand for fish world over too is expected to grow to 140 M metric tons the same year. However, this has its drawbacks. "The Food in the Anthropocene" article by the EAT-Lancet Commission in 2019 has chalked out a "planetary health diet" which is characterised by a plant-forward diet, with fruits and vegetables as well as whole grains, nuts and legumes taking precedence, and minimal meat and dairy products, refined grains, added sugars or starch, and saturated fats [3]. The majority of meat consumption is driven by middle-income countries. Consumption is usually stagnant or decreasing in high-income countries, and is low in low-income countries such as India [4]. Such consumption is of great concern not only for the environment but also for the moral issues of food ethics, the health impact of meat in the form of cardiovascular diseases and animal-food borne pathogens, which are especially of concern given the COVID-19 pandemic [5,6].

Furthermore, in underdeveloped countries such as India, animal protein is often a limited resource. This is further compounded by the fact that a sizable portion of the population is lacto-vegetarian, who further lack adequate protein in their diets. In addition, with several states banning the slaughter of cows and the sale of beef, PBM and CBM provide an avenue for those seeking to eat meat without the guilt[7,8].

The introduction of PBM and CBM has great potential in emerging markets such as India [9]. As India moves from a low-income to a middle-income nation, PBM and CBM can supplement the protein needed in vegetarian diets, as well as substitute conventional meat. This review shall predominantly focus on the latest forms of plant, fungi and cellular meat, with brief mentions of traditional plant-based meat such as *seitan* and *tempeh*, as well as textured vegetable protein(TVP).

2. Discussion

2.1. The History of PBM and CBM

Plant-based proteins have been documented to have been traditionally consumed in ancient civilizations such as China and India. Many products such as *tofu*, *seitan* and *tempeh* have been recorded as protein alternatives in Buddhist and vegetarian preparations [10]. Spurred by an increased number of vegetarians, especially in developed countries, TVP was invented in the 1960s to be used in vegan versions of meat dishes [11]. However, it failed to gain popularity with ABM consumers due to its bland flavour and potential allergic reactions from soy products. Such TVP was often used as a disaster ration and for military purposes [10]. Utilizing rising new technologies used in other food products and sectors, like mixing hydrocolloids, often used as thickening agents [12] and high moisture cooking extrusion, the next round of PBM appeared in European markets in the 2000s. These were superior both texturally, as well as in flavour and used a greater variety of plant proteins and other raw ingredients in their manufacture.

2.2.Modern-day PBM and CBM

With the rising awareness about the health concerns posed by ABM, and in an attempt to cater to the tastes of conventional ABM consumers, there was a rise of companies offering PBM and CBM from the 2010s, most notable of which are Beyond Meat and Impossible Foods [10].

2.3. Production of PBM

The preparation of Plant-Based Meat mainly involves three processes:

(i) Protein isolation and functionalization: In this, plant proteins, primarily soy protein, pea protein and wheat undergo hydrolysis to improve certain properties like solubility, as well as their ability for crosslinking.

(ii) Formulation: These extracted proteins are then mixed with products like food adhesives, plant fat (mainly coconut oil or other saturated fats) and flour to develop a texture resembling meat. In this step, nutrients are also added to make their nutritional composition comparable or better to that of ABM.

(iii) Processing: This mixture then has to be worked by processes like kneading, stretching, folding etc, or be extruded to reshape the proteins in it and finally get a texture resembling conventional meat.

Some novel technologies such as shear-cell technology, 3D printing, as well as recombinant protein additives are also being used to better the organoleptic (i.e. sensory properties) of the PBM [13,14].

On the other hand, to make fungal-based Mycoprotein, *Fusarium venenatum*, a fungus is fermented in vats in a medium of salts, glucose and ammonia. As it leaves the fermenter, it is heat-treated to minimize its RNA content, and the broth is pasteurised and centrifuged to remove the liquid. This results in a doughy mixture. This mixture is then added with a protein, usually egg albumen, which helps align hyphae and cross-link them. Colour and flavour compounds are added at this stage to mimic the texture and properties of meat. This is then heated and set and then cooled and cut, and finally frozen to have the hyphae mimic the bundles of fibres formed in the muscles of animals. [15].

2.4. Production of CBM

CBM, sometimes known as culture, in-vitro, or lab-grown meat is prepared by the cultivation of stem cells from the muscles of animals such as cows, chicken, lamb etc. It involves four main steps:

(i) Isolation of muscle and fat cells: A small piece of muscle of the animal is taken with a small biopsy.

(ii) Proliferation: The stem cells are isolated from the muscle fiber by mechanical and enzymatic action, and then used for the development of new muscle tissue. These cells are then cultured using conventional methods till sufficient numbers are reached. These are then divided into batches and differentiated.

(iii) Differentiation: These are then differentiated into muscle satellite cells which are then attached to scaffolding.

(iv) Bioreactor: For large scale production, these cells are then grown in a bioreactor. But this is still in the pilot stage [16-18]

Incidentally, the idea of CBM goes back to 1930 when Frederick Smith, the then British Secretary for India, had a vision of the creation of “self-reproducing steaks” in the future, as seen from an excerpt of his essay collection *The World in 2030 AD*, which says: “It will no longer be necessary to go to the extravagant length of rearing a bullock in order to eat its steak. From one ‘parent’ stream of choice tenderness, it will be possible to grow as large and as juicy a steak as can be desired.”[19].

2.4. Nutrition and Economics

The per gram cost of the main ingredients of PBM, soybean(0.05Rs/g approx) and wheat(0.02Rs/g approx) is much lesser than conventional meat prices(0.2Rs/g for beef and 0.6Rs/g for mutton) in India. In addition, the sale and production of beef are banned in many states throughout the country, and markets like these provide an opportunity for meat alternatives [8].

However, for crop products, the processing costs of the post-harvest process make up for nearly 94.3% of retail costs, while it is only around 50% for beef [20]. Further, additional flavour and texture additives can contribute to the cost too.

On the other hand, costs for CBM can be prohibitively high. In 2013, a proof-of-concept cultured beef burger at Maastricht University is estimated to have cost $280,400 ($2,470,000/kg) to make [21]. Estimates state that CBM could be double the price of chicken. To produce on a village scale, CBM could cost anywhere between $11-520/kg depending on the medium for growth used. Invertebrate meat cell culture might be much more cost-effective in such cases. [21]

In the nutritional aspects, the protein content in PBM is comparable with ABM. Nevertheless, to ensure a balanced amino-acid profile, formulations containing several plant proteins are necessary. (Table 1)

Table 1: Essential amino acid profile of different protein sources (g amino acids per 100 g) [15].

	Animal-Based Protein		**Plant-Based Protein**		
	Beef	**Cow's Milk**	**Soy Isolate**	**Soy Concentrate**	**Mycoprotein**

Histidine	0.3	0.09	0.6	0.4	0.39
Isoleucine	0.87	0.2	1.1	0.8	0.57
Leucine	2.53	0.32	1.8	1.3	0.95
Lysine	1.6	0.26	1.4	1	0.91
Methionine	0.5	0.08	0.3	0.2	0.23
Phenylalanine	0.76	0.16	1.1	0.9	0.54
Tryptophan	0.22	0.05	0.3	0.2	0.18
Threonine	0.84	0.15	0.8	0.7	0.61
Valine	0.94	0.22	1.1	0.8	0.6

Processing techniques such as heating and sprouting can work to improve digestibility. Although PBMs have higher dietary fibre and minerals, and less cholesterol in comparison to ABM, there are some concerns regarding the presence of Leghemoglobin in some PBMs(Impossible Foods), citing some correlations between intake of heme and a higher risk of diabetes [22]. In addition, PBMs contain a greater amount of sodium than ABM. Nutritional value of some popular PBMs in comparison to Beef Burgers is listed in Fig 3.

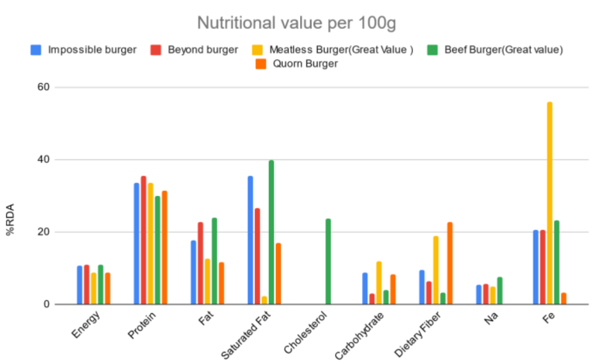

Fig 1: Nutritional Value of some popular meat alternatives compared to beef burgers for 100g servings [23].

Although there are nutritional benefits to PBM, we do not have comprehensive nutritional data for CBM available in the public domain. Going as per the claims of the advocates of CBM of an almost identical profile to ABM, we cannot expect it to provide much greater nutritional benefit.[21]

However, instead of using plant foods like legumes, most PBMs majorly rely on purified plant protein. Such proteins are usually highly processed. This processing will not only cause the loss of nutrients as well as phytochemicals that are present naturally in otherwise scarcely processed plant products; in addition, it results in products that are extremely palatable. Albeit short-term, a controlled feeding study in 2019 showed that high ultra-processed food diets result in excess caloric intake and weight gain [24]. Therefore, we cannot directly correlate existing research on plant-based foods and trends in diets to PBM and CBM.

2.5. Environmental Factors

Both PBM(1.02 kg CO2e kg^{-1}) and mycoprotein(and 0.8 CO2e kg^{-1}) have some of the least average carbon footprints. On the contrary, with 0.0068 ha kg^{-1} beef exhibits one of the greatest land footprints. In contrast, mycoprotein is the smallest at just 0.00018 ha kg [15].

Life cycle assessments (LCA) have been released by Beyond Meat as well as Impossible Foods [25][26]. These show that their effects on eutrophication and land use requirements are significantly lower than that of beef, pork and chicken. An LCA commissioned by Beyond Meat found that their burger showed 90% less greenhouse gas emissions, and had an energy requirement of 46% less, water requirement of 99% less, and land usage of 93% less than a beef burger in the US [26]. But the energy usage of such meat alternatives has been found to be significantly higher than that of ABM(Fig 5). This illustrates the need for more independent studies on the topic. However, the greatest impact is shown by mycoprotein produced by companies such as Quorn, with the least energy, land and water footprint (Fig 4). Nevertheless, the water footprint of PBMs is predominantly determined by where the main protein

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is sourced from. Another LCA study determined that one ton of PBM utilized 3800m^3 of water on average [27]

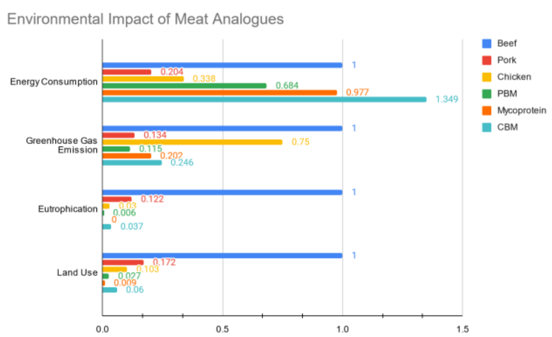

Fig. 2: Environmental impact of meat and meat analogues, normalised for beef.[21]

On the other hand, it is expected that CBM will both need fewer resources as well as lead to lesser waste emission once optimized, relative to ABM [18]. According to an LCA from 2011, CBM would have a 7-45% reduction in energy consumption, 78-96% fewer GHG emissions as well as a 99% drop in land use in addition to a water usage brought down by 82-96% in comparison to ABM [28] Another LCA in 2015, however, paints a less positive picture of reduction in footprints. In contrast, it reported that the consumption of energy, potential of acidification, as well as ozone depletion of CBM, particularly in comparison to poultry production, could be potentially more damaging than ABM. [29]. Cultured meat is estimated to have a 47% energy feed conversion efficiency in addition to a 72% protein feed conversion efficiency. While these numbers are less than those offered by PBM and invertebrate meat, they are nevertheless greater than ABM [30]

2.6. Consumer Attitudes

India has recorded a high consumer acceptance of PBM at 94.5% [31]. This might be a result of the general consensus that vegetarian and vegan diets are more often seen as healthier and sustainable by vegetarian individuals and that nearly 34% of Indians are vegetarians [11] However, studies show that it is mostly the non-vegetarian, affluent groups, and people with more education and knowledge of PBM, who are interested in PBM as consumers [10].

On the other hand, CBM is generally targeted at consumers that currently eat ABM. In India, PBM has been found to have consistently greater approval than CBM [9]. This may be due to religious and personal beliefs. There is, however, still a sizable majority appreciating it as animal-friendly, healthy and safe [32].

It is, however, possible to engineer both PBM and CBM to mimic the look and texture of ABM, as listed in Table 2. To increase the chances of success with the Indian consumer, CBM has to be comparable or superior to ABM from an organoleptic point of view [21].

Table 2: Possible ways to engineer PBM and CBM to mimic ABM **[21].**

	Plant-Based Meat	**Cell-Based Meat**
Colour	Use of heat-stable fruit and vegetable extracts (e.g., apple extract, beet juice) or recombinant heme proteins (eg, leghemoglobin) as colour additives.	Extracellular heme protein (e.g., myoglobin) supplementation or increasing intracellular expression to regulate colour.
Structure	Generation of fibrous structure by screw extrusion or	Aligned scaffolds or cell alignment during differentiation can be used to control

	shear-cell technology. Fungi are inherently fibrous.	muscle fibre structure.
Marbling	Use of visible plant fats(e.g., coconut oil, cocoa butter) for marbling.	Culturing and differentiation of fat cells(i.e. adipocytes) for cell-based fat. Adipose tissue and skeletal fat can be grown together or combined post-harvest.

2.7. Upscaling and Future Prospects

Although the per capita meat consumption of Indians is far less than their western counterparts [9], from an environmental, as well as public standpoint, shifting the growing meat demand in the Indian populace from ABM towards a more sustainable and healthier PBM is ideal. For instance, if the whole population adopted a diet, that was more affluent, with high meat content it would lead to a 19-36% rise in Green House Gas emissions, water footprints, and land requirement [33]. Despite being one of the most sustainable on the planet, the dietary guidelines issued by the National Institute for Nutrition (NIN) of India call for a greater consumption of meat and fish, which while advantageous for food security, will have environmental consequences [9].

With many scientific issues to resolve, cell-based meat research, whether in academic or private labs, remains at the experimental stage. For it to ever be an alternative commercially, the industry needs to find ways to produce tissue at an unprecedented, industrial scale.

3. Conclusion

There has been a huge shift in global food systems in the past few years, driven by the complex interplay of population growth and a need for sustainability [15]. India, due to its population and sizable agricultural industry holds a key to the future of the globe. While there has been some awareness about PBM and CBM in the western market, the Indian market is still a grossly unexplored one. As India shifts towards a more affluent diet, it is critical that PBM and CBM grow to become more viable alternatives in the future to avoid substantially large carbon and water footprints.

Further, there is a need for more exploration and research into this topic, especially from an Indian lens [10]. There is a need for more local, as well as international players to cater to the unique needs of the Indian market.

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