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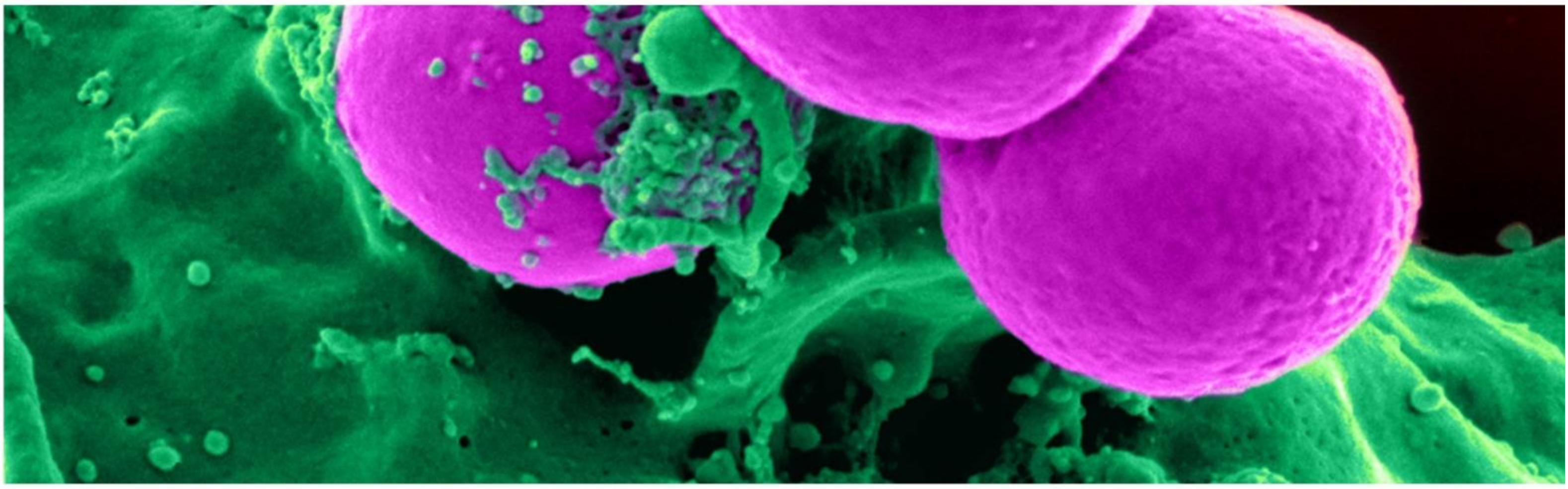

BIOLOGICAL WEALTH FOR ECONOMIC PROSPERITY

CHAPTER 05

Fungi-based meat analogues: Next generation meat alternatives

D.L.P.E. Gunasekara[1] and C.M. Nanayakkara[1,2*]

[1]Sri Lanka Institute of Biotechnology (SLIBTEC), Pitipana, Homagama, Sri Lanka.

[2]Department of Plant Sciences, Faculty of Science, University of Colombo, Sri Lanka.

*chandi@pts.cmb.ac.lk

Abstract

As part of their dietary habits, people worldwide including Sri Lankans are looking for nutritionally rich and ecologically sustainable foods due to the concerns about animal suffering and the adverse effects on human health and the environment. Fungi-based meat analogues, especially mycoproteins, have been studied for their ability to resemble animal meat in terms of taste, texture, and sensory and olfactory properties. The nutritional value is similar to that of meat proteins, making it a better choice over plant-based proteins. Based on the high carbohydrate-to-protein conversion rates, the microfungi *Fusarium venenatum* Nirenberg and *Aspergillus oryzae* (Ahlburg) E. Cohn are commonly used to produce mycoproteins using submerged fermentation. The main challenge in popularizing mycoproteins in Sri Lanka is the cost-effective manufacture. Product diversification and alternative technologies to circumvent the requirement of submerged fermentation, which is costly, are gaining momentum. Campaigns along with technological development are needed to improve consumer knowledge and make mycoproteins a viable, cost-effective meat replacement in the near future in Sri Lanka.

Keywords: *Fungi-based protein, Mycoprotein, Sri Lanka, Vegetarian*

The global search for innovative protein sources

The projected global population is estimated to reach 8.5 billion by 2030 and 9.7 billion by 2050, according to the United Nations (2022). With this population growth, there will be an increased demand for meat production, which is currently the most popular source of protein. However, it is important to acknowledge that meat production has significant negative environmental impacts, including deforestation, greenhouse gas emissions, water pollution, and biodiversity loss (Katare et al., 2023). Additionally, excessive meat consumption has been linked to various health risks, such as cardiovascular diseases, obesity, and certain types of cancer. The high levels of saturated fat, cholesterol, and sodium found in meat products contribute to development of these conditions (Geiker et al., 2021). Research has also indicated that processed meats, like bacon, sausage, and hot dogs, are associated with an increased risk of colorectal cancer (Cantwell and Elliot, 2017).

Moreover, the way meat is produced and processed can pose additional health risks. The use of antibiotics and growth hormones in livestock farming has been linked to antibiotic resistance and other health issues (Herago and Agonafir, 2017). Furthermore, the handling and processing of meat can increase the risk of foodborne illnesses (Lee and Yoon, 2021). Conversely, studies have shown that adopting a plant-based diet can offer health benefits, including a reduced risk of heart disease and certain types of cancer (Qin et al., 2022).

It is worth noting that approximately 1.5 billion people worldwide, which accounts for 22% of the global population, identify as vegetarians (Dorgbetor et al., 2022). For 75 million of these individuals, vegetarianism is a personal lifestyle choice driven by concerns about animal welfare, the environment, and personal health. In contrast, for others, poverty leaves them with no alternative (Dorgbetor et al., 2022). The growing prevalence of veganism/vegetarianism is evident in the reduced demand for meat products, the increased availability of vegan/vegetarian options in supermarkets and restaurants, and the rising number of plant-based choices at social gatherings and events. Additionally, celebrities, athletes, and influencers' endorsement and adoption of vegan and vegetarian practices have further contributed to its visibility and acceptance in mainstream society.

Mycoproteins as fungi-based meat analogues

Literally, mycoproteins insinuate proteins from fungi. It is a protein-rich food made of filamentous fungal biomass (Filho et al., 2019). The Food and Drug Administration (FDA) in the United States has designated mycoproteins as Generally Recognized as Safe (GRAS) since 2002, indicating that they pose no health risks and can be consumed as an alternative to meat or as a base ingredient in various food products (Denny et al., 2008). *Fusarium venenatum* Nirenberg and *Aspergillus oryzae* (Ahlburg) E. Cohn are commonly used to produce mycoproteins due to their high carbohydrate-to-protein conversion rates (Denny et al., 2008). The filamentous nature of fungal bodies gives mycoproteins a fibrous texture, making them suitable for mimicking the texture of meat in meat analogues. They can be processed into various forms, such as nuggets, cutlets, and grounds, making them versatile for use in different food products.

Mycoprotein can be grown vertically in airlift pressure cycle fermenters, which require minimal arable land compared to animal or plant-based protein sources (Finnigan, 2011). High-quality mycoprotein biomasses with excellent nutritional value can be produced by using specific microbial strains and substrates under specific conditions. Research indicates that mycoprotein has a lower environmental footprint per unit of mass compared to animal-derived proteins (Tuomisto, 2022). Studies also suggest that by replacing 20% of ruminant meat consumption with microbial protein derived from fermentation, deforestation and related carbon dioxide emissions could be halved by 2050 while reducing methane emissions and offsetting global pasture expansions (Humpenoder, 2022).

In terms of nutrition, mycoprotein contains valuable nutrients suitable for all age groups. It provides all nine essential amino acids and has a high-quality protein digestibility-corrected amino acid score of 0.996 (Derbyshire and Delange, 2021). According to European Commission standards, mycoprotein is classified as a high-fibre food, providing at least 6 g of fibre per 100 g of mycoprotein (Derbyshire and Delange, 2021). It is low in total saturated fat and contains very little cholesterol. Mycoprotein also offers several micronutrients of concern in vegetarian diets, such as vitamin B12, riboflavin, folate, phosphorus, choline, zinc, and manganese (Derbyshire and Delange, 2021). Plant-based proteins often lack certain amino acids like lysine, methionine, isoleucine, threonine, and tryptophan, with lysine being the most commonly absent, particularly in cereal grains (Craig, 2010). Fungi provide all the necessary nutrients for a vegetarian diet and have a low caloric value, making mycoproteins a healthy substitute for meat (Table 1). Combining mycoproteins with other plant-derived foods can address malnutrition concerns.

Furthermore, mycoproteins are less allergenic compared to common food allergens such as soy, gluten, and beef, making them a suitable option for individuals with food allergies. Additionally, the consumption of mycoproteins has been associated with the reduction of non-communicable diseases such as hypercholesterolemia and diabetes (Derbyshire and Delange, 2021).

Table 1: Comparison of the nutrition profile of fungi-based food with that of plant-based food and animal-based food.

Nutrients	Fungi-based food		Plant-based food		Animal-based food	
	Myco-proteins	Mushrooms	Tofu, Soya-beans	Chickpeas	Chicken Breast	Beef mince
Energy (kcals/100 g)	85	55	73	129	160	209
Protein (g/100 g)	11	1.6	8.1	8.4	28.4	21.8
Carbohydrates (g/100 g)	3	12.3	0.7	18.3	0.0	0.0
Fat (g/100 g)	2.9	0.2	4.2	3.0	5.2	13.5
Of which saturates (g/100 g)	0.7	0.1	-	0.29	29.6	47.5
Fibre (AOAC) (g/100 g)	6	N	-	7.1	0.9	0.0
Vitamin B6 (mg)	0.1	N	0.07	0.38	0.36	0.17
Vitamin B9 (µg)	114	N	15	35	6.0	5.0
Vitamin B12 (µg)	0.72	0.0	0.0	0.0	Tr	0.8
Calcium (mg)	48	3	N	48	9	11
Phosphorous (mg)	290	29	95	141	210	93
Iron (mg)	0.39	0.4	1.2	1.9	0.5	0.83
Magnesium (mg)	49	14	23	44	25	11
Zink (mg)	7.6	N	0.7	1.1	1.1	2.1
Potassium (mg)	71	120	63	281	270	163
Choline (µg)	180	NR	NR	NR	NR	NR

Source: Derbyshire and Delange, 2021

Production of mycoproteins

Production of mycoproteins involves the use of solid-state fermentation (SSF) and liquid-state fermentation (LSF) or submerged fermentation (SuF) methods. The choice of method depends on factors such as product requirements, production scale, available resources, and process control considerations (Adamatzky, 2021). The production process can be summarized as follows: the fungus is initially cultivated in an aerobic fermentation system, primarily LSF/SuF, using carbohydrate and nutrient substrates (Finnigan, 2011). Once the fungus mycelium is fully grown, it is heat-treated to kill the fungus and facilitate the release of RNA from the mycelium. After reducing the RNA levels from about 10% to 2%, the mycelium, which becomes slightly firm, is harvested as mycoproteins. In the final stages of manufacturing, the mycoprotein undergoes steaming, chilling, and freezing processes to achieve a meat-like structure resembling chicken. These processes, combined with adding egg albumen or dairy proteins to facilitate hyphae binding, functional additives, herbs, spices, and other flavours, result in a product that mimics the texture and taste of flesh (Finnigan, 2011). The process is illustrated in figure 1.

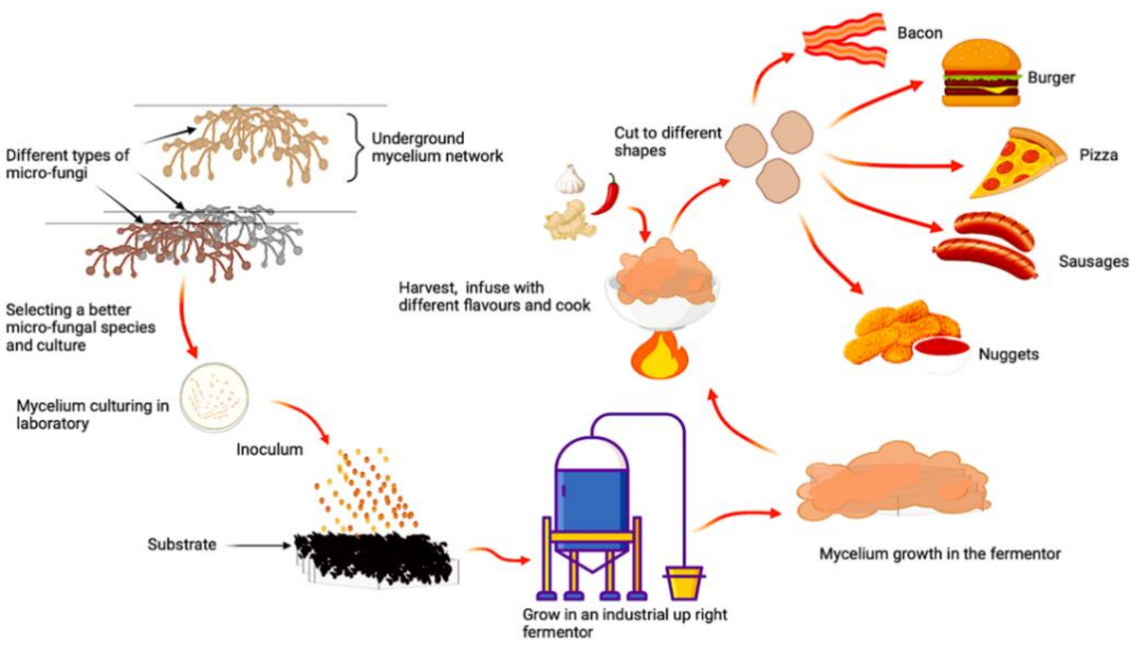

Figure 1: Graphical representation of different meat analogues production using filamentous micro-fungi

Fermentation technology in the production of protein alternatives is experiencing significant growth. According to the State of the Industry Report 2021 by the Good Food Institute, companies in the alternative protein sector raised 1.69 billion USD in 2021, triple the amount raised in 2020. Future Market Insights (FMI) predicts that the global mycoprotein industry will be valued at approximately $976 million by 2032. One well-known brand that utilizes mycoprotein in its products is Quorn™, based in the United Kingdom. Key players in the vegan meat sector in the United States include Myco Technology Inc., Tyson Ventures, General Mills, Beyond Meat, and Impossible Foods. While some companies focus on enhancing the nutritional content of mycoprotein products, others are exploring the addition of mycoprotein to meat alternatives (Future Market Insights, 2022). Mycoproteins have also made their way into the seafood sector, with companies like Aqua Culture Foods in the USA producing mycoprotein-based seafood products such as sushi, minced shrimp, tuna, and calamari for cooked dishes.

Challenges in fungi-based meat analogous production

Challenges in producing fungi-based meat analogues must be addressed to scale up production and make it a viable alternative to traditional meat. The primary challenge is the cost of production, which is influenced by factors such as the specific growth medium, energy requirements, and contamination prevention (He et al., 2020). Fungi require specific nutrients and environmental conditions to grow, and the cost of these materials can vary. Additionally, the equipment and facilities needed for production can be a significant expense. Currently, fungi-based meat production is in the early stages and has yet to achieve the economies of scale seen in traditional meat production, resulting in higher costs. However, as production methods improve and economies of scale are realized, the cost is expected to decrease. Achieving the exact texture and flavour of traditional meat can be challenging, and consumer acceptance is crucial. Texture can be improved by using different types of fungi and adjusting the production process. Additionally, mycoproteins have a slight umami flavour that can be enhanced with flavouring to create various tastes (Cordelle, 2022).

The efficient conversion of carbohydrates into protein by fungi is essential for fungi-based meat production (Lubeck and Lubeck, 2020). Researchers are exploring improved strains of fungi that can convert carbohydrates into protein more efficiently (Strong et al., 2022). They are also investigating enzymes involved in this conversion process to optimize their activity and efficiency. Genetic engineering of fungi is another approach explored to produce specific proteins with high nutritional value. Different growth conditions and substrates are also being studied to improve the efficiency of carbohydrate-to-protein conversion (Barzee, 2021).

Consumer acceptance is influenced by factors such as taste, texture, nutrition, health benefits, price, and availability (He et al., 2020). Taste and texture are crucial, as consumers expect a meat-like experience. Mycoproteins meet these expectations and provide an attractive alternative for consumers looking to reduce their meat consumption (Cordelle, 2022). It is worth noting that advancements in technology have eliminated the need for egg albumin as a binder, making some mycoprotein-based meat analogues suitable for vegetarians and gaining the approval of organizations like the Vegan Society (Finnigan et al., 2019).

Nutrition and health benefits also play a role in consumer acceptance. Mycoprotein is a rich source of protein, fibre, and other nutrients, with low levels of saturated fat and cholesterol. It has been associated with lower risks of heart disease and other chronic illnesses (Derbyshire and Delange, 2021). As more consumers become aware of these health benefits, acceptance of mycoproteins will likely increase.

Regulatory and policy implications need to be considered as fungi-based meat analogues differ from animal and plant-based products. Safety is a primary concern for consumers, as the fermentation process involved in producing mycoproteins may raise doubts about potential allergens and mycotoxins. However, the FDA and OECD have recognized mycoproteins as Generally Recognized as Safe (GRAS), and their extended history of safe use addresses these concerns.

Sri Lankan perspective on fungi-based meat analogues

In Sri Lanka, traditional meat consumption is primarily focused on chicken and beef. Plant-based meat substitutes like soy meat are popular, particularly among low-income communities. However, plant-based proteins may lack certain essential amino acids, necessitating food supplementation. The current economic crisis, exacerbated by the post-COVID situation, has resulted in a decline in purchasing power among Sri Lankans, leading to a significant prevalence of malnutrition in children and pregnant/lactating mothers. To address this issue, developing a low-cost protein source has become crucial.

Although large-scale commercial producers of fungi-based meat analogues or mycoproteins are currently absent in Sri Lanka, the opportunity exists to combat the escalating child and maternal malnutrition caused by the country's economic crisis. According to the Nutrition Month 2022 report published by the Family Health Bureau of the Ministry of Health, the percentages of undernourished children under 5 years of age, including those who are underweight, experiencing growth faltering, wasting, and stunting, have increased compared to 2021. Throughout the country, this situation spans across all age groups, from infants to children aged 1-2 years and 2-5 years.

Given that the capital and maintenance costs associated with submerged fermentation are quite high, alternative production technologies need to be adopted. Sri Lanka's abundance of cereals makes solid-state fermentation (SSF) an easily employable method. Protein bars or cereal bars enriched with mycoproteins could serve as better breakfast options for children under 5 years of age, school children, and lactating mothers. This approach would help popularize mycoprotein-based products and expand the product range without requiring significant capital investment.

While mycoprotein production currently relies mainly on the fungus *F. venenatum*, there is a global search for alternative species. Sri Lanka is home to a wide range of fungal species, including many potential candidates for mycoprotein production. The country's diverse ecosystems, such as rainforests, wetlands, and agricultural lands, host numerous fungi that can be explored for their mycoprotein-producing capabilities. Sri Lankan cuisine also includes a large number of edible wild mushrooms, whose mycelia could be potential candidates for mycoprotein production. The existence of a wide range of edible wild mushrooms provides endless possibilities for flavour and texture.

Furthermore, Sri Lanka's unique biodiversity offers opportunities to discover new fungal strains with untapped potential for mycoprotein production. Exploring unexplored habitats and biodiversity hotspots may lead to discovering novel edible fungi with superior characteristics for mycoprotein production. These newly identified strains can be studied and optimized for commercial cultivation to enhance mycoprotein yields and quality. Additionally, by utilizing locally available substrates and waste materials, such as agricultural residues, crop by-products, or organic waste, Sri Lanka can minimize resource inputs and reduce the environmental impact associated with mycoprotein production. This approach promotes cost-effectiveness and aligns with circular economy principles.

However, one potential challenge in adopting fungi-based meat analogues in Sri Lanka is consumer acceptance. Sri Lankans tend to be conservative in their food choices, and there may be resistance to trying a new protein source that is unfamiliar to them. Nevertheless, the growing interest in plant-based diets and alternative protein sources suggests that there is a definite market for mycoprotein-based meat substitutes in Sri Lanka. Another challenge is the lack of a regulatory framework for alternative protein sources in the country. While Sri Lanka has strict regulations for traditional meat products, no specific regulations currently govern the production and sale of mycoprotein-based meat substitutes. However, considering that mushrooms have been a delicacy in Sri Lankan cuisine for a long time, a similar approach can be used to promote mycoprotein-based foods.

In conclusion, the production and development of mycoprotein products in Sri Lanka have the potential to address protein malnutrition and stimulate economic growth. This endeavour could result in establishing local manufacturing facilities, generating employment opportunities, and exporting the products if they gain popularity both within the country and internationally.

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