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A review on plant-based meat analogue for sustainable environment and market scenario of plant-based meat

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Abstract
This paper attempts to describe the meat analogues that are commercially produced and are available in the market nowadays. The global demand for Plant- based meat and its by-products continuous to increase. The different meat analogue products and their protein sources, the history and the production of plant-based meat were discussed in detail are fascinating topics. Recent studies regarding the different approaches for production of meat analogues have been discussed with examples. 3D printing of the meat analogues has also been covered in the review keeping in mind its wide applicability for producing a range of meat analogues. Another distinctive area of meat analogue production focused on this review is the effect of various techniques on the different attributes of meat analogues. The effects of production methods on the attributes of meat analogues like texture, color, favor, cutting force, cooking yield, water, and oil absorption index have been discussed. This aims to address issues associated with the environmental impact, animal welfare and sustainability challenges of conventional animal farming for meat production.

Keywords: meat analogue, mock meat, quality of meat, plant-based meat

1. Introduction
Meat is valued as a complete protein food containing all the amino acids necessary for the human body. All meats contain the same three basic nutrients: water, protein, and fat. Meat is mostly the muscle tissue of an animal. Most animal muscle is roughly 75% water, 20% protein, and 5% fat, carbohydrates, and assorted proteins. Muscles are made of bundles of cells called fibers. Each cell is crammed with filaments made of two proteins: actin and myosin. There is a demand of meat among the consumers growing due to several factors. For enough proteinases' food to be produced for everyone as well as to control other harmful effects of meat production, we need to switch to artificial meat food products for protein needs. Although there are numerous arguments in favor there are very few people adopting such a diet around the world.
Cell culture developed with the help of growth factors and plant-based proteins. Meat and poultry are great sources of protein. They also provide lots of other nutrients your body needs, like iodine, iron, zinc, vitamins (especially B12) and essential fatty acids. So, it's a good idea to eat meat and poultry every week as part of your balanced diet. Meat analogues present a clear advantage to meat when it comes to shelf life and food safety. Characteristics of meat analogues are Factors include the ability to encapsulate fat, their oil, water-holding, capacity, gelling, and emulsifying properties, which can be evaluated through texture analysis. Instead of using various plant protein sources, different kinds of food additives also can enhance the textural properties of meat.

1.1 History of meat analogue and alternative meat
The concept of Plant-based meat is produced directly from plants. Instead of relying on an animal to convert plants into meat, we can make meat more efficiently by skipping the animal and turning plant ingredients directly into meat. Like animal- based meat, plant-based meat is composed of protein, fat, vitamins, minerals, and water. Buddhist monks during the Song Dynasty in China created seitan, a first plant- based meat alternative made from wheat gluten known as mean jin . this ingredient is commonly used in vegetarian dishes and favored for its meat like texture. As the name goes, plant-based meat is produced from plants. So, manufacturers do not rely on animals but on plants to make plant-based meat. Like animal-based products, plant-based meat consists of fat, minerals, protein, water, and vitamins. It's made to look and taste like meat.

Fig 1: by-product of plant-based meat

plant-based meat substitutes founded in 2009 by Ethan Brown. The company's initial products were launched in the United States in 2012. The company went public in 2019, becoming the first plant-based meat analogue company to go public.

12th or 13th Century - A Javanese manuscript refers to a tempeh-like product called kadele, believed to be the origin of tempeh. Tempeh is made from fermented soybeans & has a nutty, earthy flavour that makes it a popular plant-based meat substitute.

17th Century - Chinese immigrants brought the tofu industry to Indonesia, which is believed to have led to the production of tempeh as a by-product. As a result, tempeh became a staple in Indonesian cuisine & is now widely used as a meat alternative worldwide.

Late 1800s - John Harvey Kellogg, the creator of the famous breakfast cereal, developed "Protose," one of the first meat substitutes in the West. Protose was made from a combination of peanuts, gluten, & other plant-based ingredients & was marketed as a healthy alternative to meat.

Early 1900s - The concept of plant-based meat gained popularity in the US, & meat substitutes like nuttolene & soy-based meat alternatives were introduced. These products were made from soybeans, wheat, & other plant-based ingredients & were designed to mimic the texture & flavor of meat.

1960s - Quorn, a mycoprotein-based meat substitute, is developed in the UK. Quorn is made from a type of fungus called Fusarium venenatum & has a meat-like texture that makes it a popular alternative to meat.

1980s - Tofurky, a plant-based turkey alternative, was created in the US. Tofurky is made from a combination of tofu & wheat protein & is often served during Thanksgiving as a vegetarian possibility.

2000s - Beyond Meat & Impossible Foods, two of the biggest players in the plant- based meat market, were founded. The Beyond Burger, made from pea protein, was the first plant-based meat substitute to look, cook, & taste like beef.

2010s - Plant-based meat substitutes have gained widespread popularity, with many options available in supermarkets & restaurants worldwide. For, example, vegan milk, cheese, curd, etc. These products are made using a variety of raw materials & processing.

2020s - The meat substitute market is predicted to be worth USD 6.43 billion by 2023, with more innovative & delicious plant-based alternatives on the horizon.

As consumers become more health-conscious & environmentally aware, the demand for plant-based meat alternatives is expected to grow.

The current interest has focussed more on the direct development of non- traditional protein sources in meat analogues such as plant-based 'meat' and cultured meat. This technology can overcome the limitation of the use of conventional protein-based, especially from legumes and cereals. In recent years, the edible insect will be expected to be the prospects for human foods due to its rich in protein and good fat.

1.2. Quality of mock meat

Traditionally, the set of properties used to define the quality of meat intended for consumption as whole meat, rather than meat products, are those associated with our sensory perception; appearance, color, flavor, texture (especially tenderness), juiciness/water-holding, and odor. Mock meat is typically lower in fat and cholesterol than traditional meat and can be a good source of protein and other nutrients.

1.3 When was cell-based meat invented?

The first cultured beef burger patty was created by Mark Post at Maastricht. University in 2013. It was made from over 20,000 thin strands of muscle tissue, cost over $300,000 and needed 2 years to produce. The burger was tested on live television in London on 5 August 2013. Singapore famously became the world's first country to approve the sale of cultivated meat in December 2020 when it gave the go-ahead for Eat Just chicken nuggets.The first patent for industrial production of in- vitro meat for human and animal consumption was granted to Willem Frederik Van- Eelen in 1999 [38]. In 2002, National Aeronautics and Space Administration (NASA) scientists successfully cultured muscle tissue from common goldfish. The first cultured meat eaten by humans was by the efforts of the bio-artist, Oron Catts, In his 2003 project, Disembodied Cuisine, Oron Catts obtained cultured meat from a frog and served them as tiny frog steaks during a dinner at a museum in Nantes, France. Cultivated meat will increase access to food and, as a result, can potentially reduce world hunger. Cultivated meat uses a fraction of the natural resources used by conventional meat and does not require the raising or slaughtering of animals because sourced cells grow indefinitely.

2. Plant based meat

Plant-based meat analogs are designed to improve the nutritional functionality of the product. Generally, the plant-based meat analogs contain high protein with essential amino

acids and low-fat content which makes these products good for human health (Kyriakopoulos *et al*., 2021). Additionally, the textural and fluid/water holding capacity of the meat analogs are improved by adding dietary fiber to the product (Bakhsh *et al*., 2021a). Despite considerable nutritional characteristics, the behavior of these nutrients in the gastrointestinal tract is still questionable (Lee *et al*., 2020). Therefore, the proper understanding about the mechanism of gastrointestinal fate of the plant-based meat analogs is very important which can be useful to get a better knowhow about the digestibility and bioavailability of meat analogs. Plant based meat analog production is a strategy for simulating a novel form of meat and has driven the interest of researchers in replacing animal meat consumption. However, there are some challenges in the development of plant-based meat analogs in terms of texture, nutrition, and sensory properties. Three-dimensional (3D) food printing can be used to manufacture food with customized shapes, colors tastes, textures, and nutritional value. Therefore, 3D-printed plant-based meat analogs have technical and commercial potential, but further research is needed to better understand their applications and limitations.

Algae based meat analogue

Some algae, particularly blue-green and green algae, contain very high levels of protein, typically 40 to 60% (of dry matter), that can be used as functional food ingredients. Algal proteins possess a high nutritional value in terms of protein content, amino acid quality and nutritional acceptability. Their functional properties, such as gelation, water and fat absorption capacity, emulsification capacity, foaming capacity, etc., are also comparable with those of terrestrial plants. Besides their natural character, other important aspects related to the algal proteins are their easy cultivation, their rapid growth, and the possibility to control the production of some specific compounds by manipulating the cultivation conditions. Algal proteins possess a great economic potential for use in functional, processed foods and health foods.

Mushroom- based meat analogue

Mushroom based meat analogue used as plant-based protein in meat and adding of Mushroom gives the flavor of conventional meat. It contains alkaloids and flavonoids, vitamin D, B2,3 and 5 and they are naturally high-fiber single -cell protein (SCP). Benefit of adding Mushroom in meat analogue preparation is it act as immune system enhancer and cholesterol lowering agent. The portobello Mushroom crowns are the superior beef replacement due to their satisfying texture and array of the flavor. This meat is made from both the fruiting bodies and root systems of three types of mushrooms (Shiitake and white button) along with chickpea, soybean flour, Wheat flour vegetable oil and water. These ingredients come together to create a succulent vegan meat.

soy-based meat analogue

Soy us the major source of plant-based protein and commonly used in meat analogue.

The nutritional composition of soybean flour was moisture 1.4%, protein 49.3%, fat 24.9%, fibre 3.0% and total carbohydrates 18.6%. Soy is rich in vitamins, minerals, isoflavones and help lower cholesterol. Soy is strongly recommended for diabetics, expectant mothers, growing children, cardiac patients . Soybean is suitable and free to consume for all people so when it is added as a major source in plant- based meat, everyone from children to aged can consume meat without any hesitation especially cardiac patients.

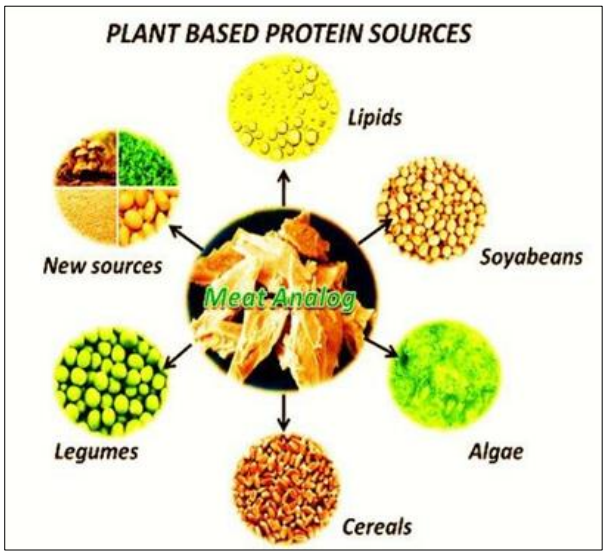


Fig 2: Plant-based protein used for meat analogue production

3. 3D foot printing

Founded by entrepreneurs Eshchar Ben-Shitrit and Adam Lahav, Redefine Meat (formerly JetEat) produced its first 3D-printed plant-based steak in 2018. The company says its patented industrial-scale digital manufacturing technology manages to fully replicate the muscle structure of beef. 3D printed vegan meat may appear unattractive, but the meat printing procedure is both organic and straightforward. Breaking down the components of meat into three primary components: blood, fat, and muscle is the most advanced way, and most industry pioneers adopt it. Since 3D meat is made of plant-based ingredients or cultured cells, its nutritional value is typically much higher than regular meat. These alt-meats provide more nutritious supplements without any harmful content, like unhealthy fats.

4. Global demand of plant-based meat and its by-products

Global production and consumption of meat continue to surge as demand is driven upward by population growth, individual economic gain, and urbanization. Is food security in the context of the current and projected dramatic increase in global demand for animal products compatible with environmental sustainability? The answer to this question must be considered against the backdrop of the world's demographic explosion and the increase in wealth among large segments of the population in transitional and developing nations. These changes result in a huge growth in global demand for animal-derived goods, particularly meats and dairy products. Industrial animal production is inherently resource-inefficient and environmentally damaging, rendering the current food system environmentally and societally unsustainable. In this part, we suggest that for a sustainable future, huge sectors of the world's population must drastically reduce their intake of meat and dairy foods. As a result, plant-based diets are required on a global scale.

The global plant-based meat market size was valued at USD 4.40 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 24.9% from 2023 to 2030.

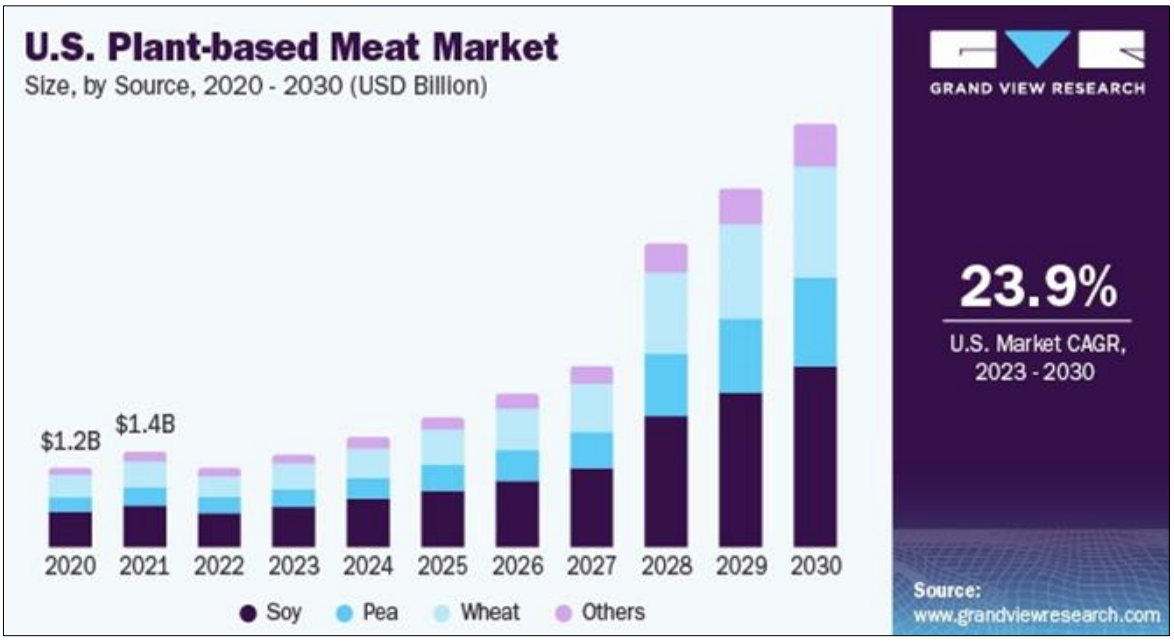


Fig 3: Analysis% of plant-based-meat

There is a growing recognition of the urgent need to change citizens' lifestyles to realize de-carbonized societies. Consumption-based accounting (carbon foot-printing) is a helpful indicator for measuring the impacts of peoples.

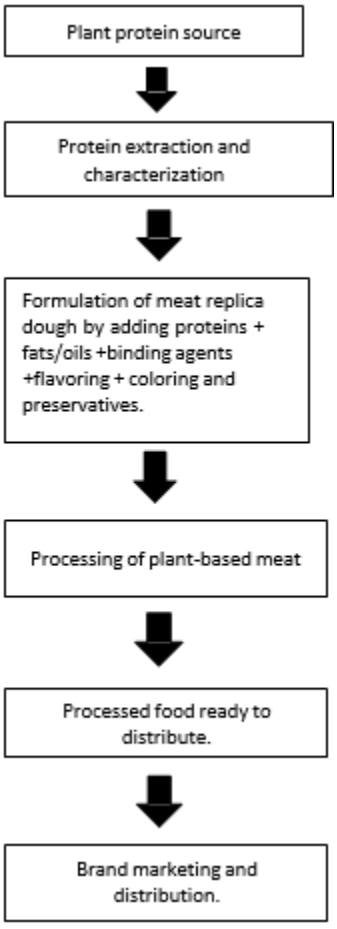
5. Carbon Foot printing

consumption on climate change by capturing both direct and embedded carbon emissions. The carbon footprint for food waste is defined as the amount of GHGs emitted during the production and treatment of the food waste equivalent to the radiative forcing exhibited by the unit CO2 emitted; the amount of GHGs is, thus, usually expressed in kilograms of CO2 equivalent (kg CO2 eq.). Carbon footprint of meat in India has been estimated that over 200 million tons of CO2 equivalents are released by Indian livestock each year. Overall, animal-based foods tend to have a higher footprint than plant-based. Lamb and cheese both emit more than 20 kilograms CO2-equivalents per kilogram. Poultry and pork have lower footprints but are still higher than most plant-based foods, at 6 and 7 kg CO2-equivalents, respectively.

6. Methods on the attributes of meat analogue

Typically, the production of PBM includes three steps: (i) Protein isolation and functionalization—Target plant proteins are extracted from plants, some of which are subjected to hydrolysis in order to improve their functionalities such as solubility and cross-linking capacity; (ii) Formulation—The plant proteins are mixed with ingredients to develop meat texture such as food adhesives, plant-based fat and flour. Nutrients are added to match or exceed the nutrient profile of the meat. (iii)

Processing—The mixture of plant proteins and other ingredients undergo protein reshaping processes (e.g., stretching, kneading, trimming, pressing, folding, extrusion, etc.) to form a meat-like texture. Innovative technologies being utilized to improve the organoleptic properties of PBMs include shear cell technology, mycelium cultivation, 3D printing, and recombinant protein additives.



7. Benefits of Eating Plant-based meat

Plant-based alternatives to meat and dairy products can give the same, if not more, minerals and protein. In fact, as numerous alternatives on the market have demonstrated, there is a long list of reasons why you should eat plant-based:

1. Lower in saturated fats
2. Assist with cholesterol reduction
3. Assist in lowering cardiovascular risks
4. Aside from health benefits, plant-based alternatives have

been proved to be a better option for the environment:

5. Reduce your reliance on more resource-intensive manufacturing techniques.
6. Reduce greenhouse gas emissions
7. When compared to conventional meat production, require less water and land.
8. Finally, the benefits of eating conventional meat products outweigh the benefits of eating healthy alternatives.

8. Effects of production method on the attributes of plant-based meat

8.1 Texture

Since plants lack muscle tissue, it is difficult to replicate the feel of animal proteins using plant-based components. Plant cells are hard and unyielding, whereas muscles are elastic and stretchy. Because plants lack the snap and chewiness of meat, veggie burgers frequently come across as crumbly and mushy.

8.2 Cutting force

Hardness and fibrous structures are indirectly measured by cutting force based on degree of texturization or hardness. With increasing protein concentration, the cutting force decreased significantly, indicating that the formation of fibrous structures is diminished. The cutting force increased as the temperature increased, but only at higher temperatures. Perhaps higher temperatures result in more denaturation of proteins. An increase in screw speed was responsible for a significant increase in the cutting force of meat analogues. The effect of extrusion temperature, and screw speed on cutting force is consistent with the studies of Grahl *et al*. (2018). The sensory acceptance of meat analogues can be influenced by both the hardness and the level of fibrousness/texturization.

8.3 Flavor

Vegan meat flavor can be generated by thermally treating raw materials such as yeast extract or hydrolyzed vegetable protein (Lin *et al*., 2014; Wu and Cadwallader, 2002a). Flavor is a crucial sensory attribute of food products, just like texture and aroma. So, plant-based meat products might be tasty, and grilling them might help release some meaty aromas, but they are not necessarily as good for you as the veg they're made from. Animal-based fats have a unique profile that is hard to replicate with plant-based fats.

8.4 Cooking yield

Plant-based meat cooks faster than regular ground beef—thick plant-based burger patties, for example, take just 2 to 3 minutes per side compared with 3 to 5 minutes per side for similarly thick beef patties—be sure to begin checking for doneness on the early end of the time range to guard against overcooking. The amount of water absorbed during cooking also affects sensory properties, such as juiciness. By increasing the temperature and screw speed, and decreasing the water feed and protein concentration, resulted in hard products exhibiting higher cutting force and cooking yield.

8.5 Water and oil absorption index

The oil holding capacity (OHC) of proteins is important to understand since this affects their emulsifying properties (Biswas & Sit, 2020). Accordingly, the oil absorption index of the extrudates increases with higher barrel temperatures and decreases with higher screw speeds. The increased oil absorption is possibly due to the degradation of starch in the extrudate due to high thermal energy input (Omohimi *et al*., 2014).

The water absorption index (WAI) measures the volume occupied by the granule or starch polymer after swelling in excess of water. The ground extrudates were suspended in distilled water vat room temperature for 30 minutes, gently stirred during this period and then centrifuge at 3000 rpm for 15 minutes. 17.38 to 366.56% Water absorption capacity is defined as the amount of water that can be hold to the TVP structure after rehydration (Lin *et al*., 2002). The range of WAC of TVP was from 217.38 to 366.56%.

9. Future perspective

Many scientists are concerned about the reductionist approach of simply adding isolated forms protein, vitamins, and minerals to foods, or diets in general, and designating them as nutritionally adequate (Lichtenstein and Russell, 2005; Jacobs and Tapsell, 2007). As whole foods contain hundreds-to-thousands of compounds that act synergistically to impact human health (Barabási *et al*., 2019), adding synthetic nutrients to food sources often does not confer similar benefits compared to when these nutrients are ingested as phytochemically and biochemically-rich whole foods—whether it be plant or animal foods. Humans satisfy requirements for certain nutrients much better from plant foods, while needs for other nutrients are met more readily from animal foods. Plant nutrients (i.e., phytochemicals) often protect against potentially harmful compounds in cooked animal foods.

vegetarians and meat-eaters alike can benefit from protein-rich legumes and cereals. Until the market for meat substitutes matures, food scientists and entrepreneurs will have numerous possibilities to test fresh conceptions. It has been a key focus of product growth and applied research for many years to advance meat substitutes that feature texture-related sensory qualities Plant proteins can be altered into fibers or non-filamentous protein aggregates using old and emerging technologies. Plant proteins have not yet been able to produce myofibrils, muscle cells, and muscle tissue, as well as their water-binding (juiciness) and mouthfeel qualities. With new plant-based meat alternatives that mimic meat better and the development of lab-grown meat, it is important to better understand consumers' preferences for these meat alternatives.

This study provides insights the new alternatives are being marketed by start-up companies with a strong interest in touting the benefits of their products, the impact of different information and the presence of brands on choice was also tested. Overall, study finds that information only has a small impact on consumer choice although the impact varies depending on the types of benefits communicated to the consumers. For instance, providing information on environmental and animal welfare benefits of the meat alternatives has the largest effect on the share of consumers with positive preferences for lab-grown, plant-based using pea protein and using animal-like proteins produced by yeast, respectively. If we improve both the efficacy of proteins (better function) and the overall quality of developed products, we can increase market volume due to increased consumer acceptance. In deduction, plant-based Protein supplements are a nutritional alternative, but they are unlikely to replace traditional meat and poultry products in the future.

Animal meat remains in high demand around the world. Meat, on the other hand, will remain a primary source of protein. To ensure a sustainable source of protein, use "meat alternatives" or "meat substitutes" instead of sausages, burgers, and other meat-based goods. Vegan meat consumption over the meat provides many health benefits such as protection against heart disease, lower blood cholesterol, reducing the risk of cancer and increasing bone mass (Sadler, 2004). Food scientists by studying the present situation are now creating meat alternatives that truly taste like meat and have the same “mouth feel” their nature made counterparts. To keep up with the world's population expansion, scientists and food processors are attempting to supply the most organic and nutrient-rich meals possible from sustainably derived plant protein sources. However, the research should be directed on developing innovative strategies for lowering product costs.

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