

## REVIEW ARTICLE

# Meat Product Analogues – Consumers’ Perspective and Available Production Technologies and Market Offerings

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**Abstract**

In recent years, the market for plant-based products and, in particular, plant-based alternatives to meat has been growing rapidly. Consumer interest in a vegan diet and the purchase of substitutes for animal products, including meat analogues and meat products, is also growing significantly. The aim of this study was to provide an overview on alternatives to meat products, focusing on plant-based alternatives to meat as well as cultured meat. The article points out that there are three main groups of reasons why people choose a vegan diet, these are environmental, ethical and health reasons. The article also discusses the topic of meat substitutes. Various food groups that can be alternatives to meat in the diet are identified, such as plant-based meat substitutes, edible insects and cultured meat, or so-called clean meat. The focus of the research is on the promising topic of plant-based meat substitutes. The techniques used to produce plant-based meat alternatives are also discussed, focusing on three of them, i.e. extrusion, fibre spinning and 3D printing. Problems encountered in the production and consumption of plant-based meat analogues were pointed out, including the lack of or insufficient acceptance of sensory attributes by consumers. The topic of cultured meat as another alternative to traditional meat was also presented.

**KEYWORDS**

plant-based alternatives to meat, meat substitutes, plant-based diet

**Introduction**

The market for plant-based meat alternatives has been growing in recent years. By value, global sales of plant-based meat alternatives totalled \$10 billion in 2018 and are projected to triple by 2026, but even so, this volume still only represents 4% of traditional meat [Waston 2019]. According to a Smart Protein Project study, which included European countries such as Austria, Belgium, Denmark, France, Germany, Italy, the Netherlands, Poland, Romania, Spain and the UK, the value of vegan sales increased by 49% from 2018 to 2020, with the market dominated by soy products [Smart Protein Project 2020]. According to an Omnibus Online Survey conducted in January 2021, it was found that vegan food is occasionally reached for by at least a third of respondents [www.imas.pl]. More and more people are also declaring themselves vegan or vegetarian. According to the Roślinniejemy re-

port, 8.4% of respondents have already identified themselves as vegetarian or vegan. More and more people are also consciously giving up dairy products, or eggs [Raport Roślinniejemy 2019]. According to the Vegetarian Society of the United Kingdom in recent studies even higher numbers of vegetarians are reported, but the term “vegetarian” is not clearly defined, thus results may be overestimated [https://vegsoc.org].

According to Smart Protein’s report ‘Evolving appetites: an in-depth look at European attitudes towards plant-based eating’ in November 2023, the number of people declaring reduced meat consumption is 51% of respondents, five percentage points higher than in an identical survey from two years earlier. Those who declare themselves flexitarians are 27% of those surveyed, and the highest number of flexitarians among the countries surveyed

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is in Germany (40%), Austria (37%) and the Netherlands (35%). The research also indicates a significant number of people on a vegetarian diet and this is 5% of those surveyed, with the UK (7%) and Germany and the Netherlands (6%) in particular having the highest numbers. Vegans accounted for 3% of all respondents, with the highest proportion in countries such as Austria (5%), Germany (4%) and Denmark and the Netherlands (3%). Among the countries surveyed, Denmark stands out, with the highest consumption of vegan products. Beef and pork were the products most frequently ignored by consumers (approximately 30%). People on a vegan diet are more likely to be younger people, in particular people from generation Z (1997-2012) who consume plant-based products most often. Among respondents from this generation, this was the highest percentage, with 7% of respondents; by comparison, in the Boomers generation (1946-1964), only 3% declare themselves as vegans. A growing group irrespective of generation are flexitarians who limit their consumption of animal products, they account for between 26 and 29% of respondents. Flexitarians are much more likely than people on a traditional diet to turn to plant-based alternatives to animal products, which is particularly evident in products such as dairy substitutes, milk, yoghurt and cheese. The most commonly consumed plant-based products are: legumes - 31% of respondents declared consuming them regularly, followed by plant-based milk substitute drinks - 19% of respondents consume them regularly, and then plant-based substitutes for fish and seafood. The most unfamiliar and least consumed products were tempeh and seitan, while tofu was the most frequently tried product but not included in the respondents' regular diet. [Evolving appetites..., 2023].

The aim of this study was to provide an overview on alternatives to meat products, focusing on plant-based alternatives to meat as well as cultured meat and production technologies and consumer outlooks.

During the literature review, a Google Scholar database was searched. The search was based on the following keywords: meat analogues, meat alternatives, vegan food, veganism, clean meat. The search included papers published in the last 10 years up to June 2024. After an initial review of the titles and abstracts of the papers, 50 were selected as the best fit for the review, and after reading the selected articles, the ones used in the paper were selected.

Reasons for the interest in plant-based products and diets Increasing interest in plant-based products and plant-based diets is evident in many countries. People are choosing plant-based diets for a variety of reasons [de Villiers et al. 2024]. The most commonly cited ones are environmental concerns, ethical considerations as well as health reasons [Gryza 2017, Wydrzyńska 2018], as well as taste, antibiotic concerns, social considerations and large outbreaks of animal-to-human transmissible viruses such as

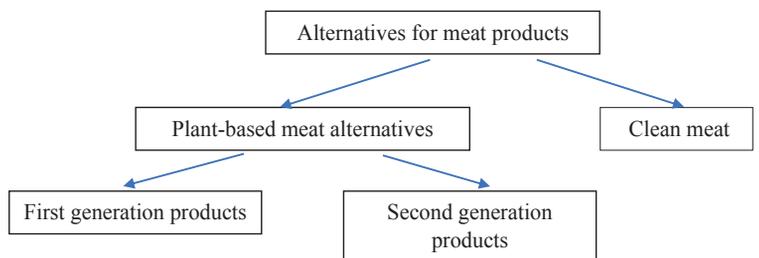
COVID-19 [Evolving appetites... 2023]. Environmental issues and the desire to minimise climate change are very important and frequently mentioned by respondents. Decisive reductions in the amount of greenhouse gas emissions in the atmosphere, reduction of water consumption, improvement of air quality were pointed out [Gryza 2017; Wydrzyńska 2018]. The ethical issues driving people to switch to veganism are diverse. Among others,

veganism can be mentioned as a tool for social change being more favourable to non-human beings, the welfare of farmed animals is very important, and the issues of their breeding, especially mass production and slaughter [Gryza 2017]. Positive effects on health, body shape and fitness have also been pointed out, nevertheless these reasons are less frequently mentioned by respondents and improved health is said to be an add-on, a positive effect of a plant-based diet for ethical or environmental reasons [Wydrzańska 2018]. Other sources indicate that health is the main reason for reducing meat and dairy product consumption. This is particularly evident among the oldest respondents, where a group as high as 57% of respondents indicated this reason [Evolving appetites... 2023]. This may be related to the fact that a diet containing red meat as processed meat is associated with an increased risk of diseases such as cardiovascular disease, heart attack and cancer, as well as increased mortality. In contrast, a plant-based diet is associated with positive health effects such as reduced risk of type II diabetes and cardiovascular disease [Eckl et al. 2021].

**Alternatives to meat products**

Meat substitutes are a group of products that aim to replace and imitate traditional meat. Not only the taste, texture and appearance are intended to imitate those of animal origin, but also the nutritional values are very important [Starowicz et al. 2022]. These products are predominantly of plant origin - pulses, cereals, edible mushrooms or oilseeds. However, products such as farmed meat, so-called clean meat, or edible insects are also included in this group [Sun et al. 2021]. Meat substitutes fall into two main categories - plant-based alternatives to meat and pure meat (Figure 2) [Nezlek, Forestell 2022]. He and co-authors divided plant-based meat alternatives into two generations, one and two (Figure 1). He singled out as the first products that in their original form are not considered meat substitutes, they are widely known and traditional in certain countries, regions of the world. Such products include tempeh, tofu and seitan [He et al. 2020].

**Figure 1.** Distribution of alternatives for meat products. Source: Own compilation based on literature bacon [He et al. 2020; Sun et al. 2021]



**Figure 2.** Clean meat, source: <https://english.radio.cz/czech-startup-presents-unique-lab-grown-meat-prototype-8774757#&gid=asset&pid=3>

Tempeh (Figure 3) is a product that originated in Indonesia. It is prepared from properly prepared soya beans on which the fungus *Rhizopus oligosporus* grows [Nowak 2016].



**Figure 3.** Tempeh, source: <https://www.celestialpeach.com/blog/chinese-vegan-101-tempeh>

The history of tofu (Figure 4) dates back over 2,000 years and began in China. The production of tofu consists of many processes including soaking, milling of soybeans, heating of the soy product, filtration of the coagulant additive, extrusion and moulding [Zheng et al. 2020].



**Figure 4.** Tofu, source: <https://resepkoki.id/kenali-perbedaan-tahu-vs-tofu/>

Seitan (Figure 5) is a product made from wheat flour, through a process of leaching starch to make gluten pulp, and then cooked [Bakhsh et al. 2021].



**Figure 5.** Seitan, source: <https://www.connoisseurusveg.com/how-to-make-seitan/comment-page-3/>.

First-generation products can also include textured vegetable protein, which was first produced in the 1960s. First-generation products do not aim to imitate meat and their taste is completely different [Andreani et al. 2023]. These products are accepted by vegan consumers, however, it is the second-generation products that are more popular. These products are relatively new to the market and are growing in popularity among consumers. Second-generation products are not traditional products in the cuisines of the world, but they aim to imitate meat or specific meat products as closely as possible. These products are intended to resemble the prototypes in terms of both sensory and nutritional value. Due to their meat-like sensory properties, they are met with considerable acceptance by consumers who consume animal products. Burger patties are the most popular on the market, as well as a large selection of sausages, and bacon [He et al. 2020]. Challenges for meat analogue production.

European respondents indicated several factors that are important to them when choosing plant-based food alternatives [Table 1]. The most important of these was good taste, which was indicated by more than half (53%) of the respondents, followed by the fact that they are healthy (46%) and availability (45%). Reasons such as freshness, lack of additives and artificial ingredients, availability in the shops where they shop, harmlessness to the climate and environment, pleasant texture, and being organic were also mentioned. The main barriers to choosing plant-based meat and dairy substitutes were that they were too expensive, not palatable enough and that there was too little information about plant-based substitutes [Evolving appetites... 2023]. The key to the success of plant-based meat alternatives is to imitate real meat as faithfully as possible. Taste and texture matter most to consumers [Sha, Xiong 2020]. Factors such as taste, appearance and aroma also play a huge role here, with juiciness and tenderness being the main textural attributes [Starowicz et al. 2022]. The first thing consumers pay attention to is the colour of the product. In order to get meat-eating consumers to turn to plant-based meat substitutes and change their eating habits, sensory attributes play a key role. The whole composition of the meal for which the plant product will be used is also important; it should resemble a traditional dish as much as possible [Starowicz et al. 2022].

**Table 1.** Consumer incentives and barriers to choosing plant-based meat alternatives

Incentives	Barriers
Good taste	High price
Health	Insufficient palatability
Availability	Too little information on plant-based meat analogues
Freshness	High number of ingredients and food additives
No additives or artificial ingredients	
Availability	
Climate-friendly	
Pleasant texture	
Organicity	

### Meat analogue composition

Most plant proteins are suitable for making meat analogues or analogues of other animal products. However, soya, pea proteins and wheat gluten are the most common and widely used in the industry due to their cost, availability and processing technologies [Xiao et al. 2023]. Legume proteins have a globular structure and are therefore not suitable for creating a texture that simulates that of meat. It thus becomes necessary to use techniques such as extrusion and fibre spinning, which transforms globular particles into fibrous structures. Fats are also an important component in the formation of the sensory qualities of food products; they are responsible for texture, flavour, juiciness and mouth-feel. Therefore, attention should be paid to the presence of fats in vegetable meat alternatives. Solid vegetable fats such as coconut oil and cocoa bean oil are used, mixed with liquid oils such as sunflower or rapeseed oil, as well as sesame oil and avocado oil. Another important ingredient is carbohydrate polymers, whose important role is to improve texture, bind water and reduce syneresis. These can be divided into two groups such as crude fibres from plant cell wall materials such as wheat, oats and apples, and purified polysaccharides and their derivatives. Other non-protein components that can be found in plant-based meat substitutes are adhesives, colours, flavourings, minerals, vitamins, antioxidants and antimicrobial agents [Starowicz et al. 2022].

### Production technologies

There are various techniques leading to the production of meat analogues, and depending on the source they can be divided into categories based on:

- material/protein source (plant, insects, fungi) [Lee et al. 2024]
- production strategy (top-down, bottom-up) [Singh, Sit, 2022]
- scalability [Nowacka et al., 2023].

Nevertheless commonly recognised are: extrusion, shear cell methodology, fibre spinning and 3D printing.

Extrusion is the most commonly used process in the production of meat analogues and can be applied to various protein sources. The plant aggregates obtained by extrusion can be used in many meat product analogues. The process is characterised by scalable and high production yields, energy efficiency and robustness. For the production of plant-based meat alternatives, the process involves mixing plant proteins with water, carbohydrates, salts, flavourings and fats. Once mixed, they are fed into a twin-screw extruder, where high temperatures act on them. Two types of processes can be used in the production of plant-based meat alternatives - dry extrusion, where the moisture content does not exceed 30%, and wet extrusion, where the moisture content is 40-80%. Products obtained by dry extrusion are poor in flavour, while wet extruded products have much better sensory characteristics, where texture, structure and appearance more closely mimic animal meat [Lima et al. 2022; Sun et al. 2021; Nowacka et al. 2023].

The second noteworthy technique for the texturing of meat analogues is the shear cell method, that is based on the concept of flow-induced structuring. The texturing process is performed in cone-in-cone or Couette cell devices, in which the intensive shearing of material takes place [Kołodziejczak et al. 2022]. The main advantage of shear cell texturing when compared to extrusion is that in this technique the shear conditions including forces

and temperature can be controlled, but due to being a batch process the production is less efficient [Nowacka et al. 2023]. Another technique is fibre spinning, similarly to extrusion two subtypes of spinning are employed, namely wet and electrospinning. Wet spinning was introduced in 1954 and it is usually used for soya beans, peas or beans. It involves forcing the protein into a coagulation bath that contains a solvent, containing Ca<sup>2+</sup>, causing the protein to precipitate and the shearing forces to create stretched fibres. Subsequently, the material is separated and washed. With the help of binding agents, this material is formed into meat analogues. This process is quite complex and requires concentrated protein solutions and is expensive, so it is difficult to introduce this process on a large production scale [Lima et al. 2022; Sun et al. 2021]. Electrospinning is more sustainable and based on pushing a charged biopolymer solution out of the nozzle, resulting in rapid evaporation that leads to the formation of a very thin fibre that can be in nanometre scale. Unfortunately, plant proteins usually do not meet the necessary conditions to process them by electrospinning, as in their native state they are globular or insoluble due to the formation of denaturated aggregates [Nowacka et al. 2023].

Three dimensional food printing is developing very rapidly, but the term may relate to different printing techniques i.e. extrusion, sintering, ink-jet and bio printing [Nowacka et al. 2023]. To produce meat analogues, a method based on syringe injection is most commonly used. A protein solution of suitable viscosity is extruded through the syringe and the desired shape is formed by layering. The challenge in such products is to create suitable templates and materials, which, once printed, are able to rapidly harden the structure, as well as being suitable for subsequent thermal processing, such as cooking or frying [Lima et al. 2022; Sun et al. 2021]. Nevertheless, 3d printing is considered as one of the most versatile methods for the production of meat analogues, both in terms of substrates as well as the products obtained. This novel technique requires further research in terms of process optimisation [Kołodziejczak et al. 2022], especially considering its major drawback which is the time consuming production process [Nowacka et al. 2023].

Some researchers have also dived into the topic of freeze structuring. This method is based on the preparation of homogenous emulsion, freezing and removal of water without the melting of ice (e.g. lyophilization). This results in a product porous structure that can appear to look like fibrous material [Lee et al. 2024].

### Cultured meat

For plant-based meat substitutes, it is very difficult or even unattainable to achieve a meat-like structure. Work on developing cultured meat strives to achieve the best and most similar structure to traditional meat [Sha, Xiong 2020]. Compared to plant-based meat analogues, of which there is a diverse selection on the market and which can be purchased in a large number of shops, pure meat is hardly available and the production techniques are limited [Nezlek, Forestell 2022]. Cultured meat is often referred to as synthetic, artificial, laboratory-reared, factory-farmed meat. Nevertheless, it is produced in a clean and controlled environment, which is a guarantee that such meat is free of many diseases such as foot-and-mouth disease or bovine spongiform encephalopathy [Sun et al. 2021]. The history of cultured meat is not long, it was only in 2012 that Danish scientist Mark Buster grew

the first artificial meat and a year later created a burger from such meat, which was sensory tested by a team at Riverside Studios in London. Three techniques are known to produce skeletal muscle and tissues such as bone, cartilage, fat and fibrous tissue, these are stem cell isolation and identification, ex vivo cell culture and tissue engineering [Post 2021]. A problem that arises during cell culture is its high consumption of energy, water and raw materials. Another problem is also the lack of acceptance among consumers, which is related to the lack of knowledge of the subject [Sun et al. 2021]. Cultured meat can have the advantage of adjusting the chemical composition of the product, for example by increasing polyunsaturated fatty acids, a healthier, dietary product can be created [Post 2021].

### Market challenges

Innovations in processing technology and modern product formulations will continue to improve the quality characteristics of meat substitutes. The inclusion of a variety of additives to achieve meat-like texture, juiciness, mouthfeel and flavour raise concerns about nutritional value, food safety, clean label, cost and consumer confidence [Sha, Xiong 2020]. This is particularly important because, studies often show that the texture and structure of plant-based meat analogues is inadequate and unsatisfactory [Starowicz et al. 2022]. One of the problems that occur in the production of products classified as meat alternatives is the high content of additives in a given product. Often the number of ingredients exceeds twenty or even forty. Additives that are found in such products include preservatives, stabilisers, and colourings. The large number of ingredients, especially additives, is not conducive to the confidence of consumers, who prefer products with a clean label [Sha, Xiong 2020]. Caputo et al. [2023] conducted research on US consumers, comparing their preferences for various types of burgers: a 100% beef burger, a plant-based burger made with pea protein, a plant-based burger made with animal protein, a mixed burger combining plant-based and animal protein, and a mixed burger with 70% beef and 30% mushroom. The study found that consumers most frequently chose the 100% beef burgers. Mixed burgers were preferred over fully plant-based options, and burgers with protein resembling animal protein were favoured over those made with pea protein. Further studies indicate that liquid additives such as water and rapeseed oil have a positive effect on the sensory profile of meat analogues and consumer acceptance. Reduced soy flavour and the increased juiciness of vegetable meat analogues were indicated. Texture parameters as a result of sensory evaluation were significantly influenced by water and juiciness by oil [Wi et al. 2020]. Other studies indicate a high acceptability of replacing chicken meat, with plant proteins. They were highly acceptable in terms of texture, aroma, colour and overall acceptability. Based on this, it can be concluded that plant proteins can replace up to 80 to 100% of the meat in sausages [Kamani et al. 2019].

### Conclusions

The growing interest in vegan diets and plant-based products is encouraging the development of new products and production techniques. Currently, there are many problems regarding the production of meat analogues, both plant-based substitutes and pure meat. Lack of consumer acceptance due to unfavourable sensory characteristics and the price of products is also a major problem. Consumers indicate a willingness to buy plant-based sweets and snacks, plant-based meat substitutes and milk

as well as other products. They also indicate the greatest trust in plant-based proteins, followed by cultured meat, mushrooms, algae-based proteins and insect-based proteins [Evolving appetites... 2023]. The growing interest in this part of the food industry by scientists is encouraging its development and indicates the potential for developing new products.

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