TRANSITION TO THE FUTURE: MEAT ANALOGUES & CULTURED MEAT

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Abstract

This paper is based on a review of the state of the art related to conventional meat replacing process for future food. This review is based on assessment of 73 articles published between 2001-2023 in order to find the main reason that led to the need to replace meat of animal origin with various meat analogues from different sources. Another objective of this study is the identification of protein sources and nutritional value of meat analogues because this issue led to the new research agendas and industrial challenges. The review of the most relevant studies on how to obtain meat analogues, such as for example extrusion for plant-based meat analogue, open research horizons in improving the sensory and textural properties of plant-based meat analogues. Consumer behaviour of replacing animal meat with meat analogues and cultured meats is not an easy task, requiring in-depth studies and research, and the risk and benefits analysis of plant-based meat analogues. As in any new product development process, this study has also revealed the results related to consumer attitude research regarding meat analogues.

Key words: meat analogues, cultured meat, sustainability, processing methods, consumer attitude.

INTRODUCTION

Globally, the excessive consumption of meat has given rise among researchers to concerns related to the environment, public health and to concerns related to ideology and ethics (Lima et al., 2022). Overall, the food sector accounts for approximately 26% of global greenhouse gas emissions (Zioga et al., 2022).

Along with vegan and vegetarian trends, many consumers are following flexitarian diets by reducing the animal food to include more plant-based food in their daily diet. Plant-based diets are beneficial for health due to reduced risk of obesity, tumors and cardiovascular diseases (Hassoun et al., 2022; Craig et al., 2021; Samtya et al., 2021).

For humanitarian reasons, vegans and vegetarians avoid animal products, but could enjoy the nutritional benefits by using alternative or no-kill foods (Kazir & Livney, 2021).

Due to the harmful effects of animal production, the direction of technological development is directed towards the need to find alternatives, such as vegetable proteins (Szpincer et al., 2022; Estel et al., 2021; Lai et al., 2017). Plant-based meat alternatives are textured food products made from plant-derived proteins that mimic or replace meat (Wang et al., 2022; Lee et al., 2020). These changes are in line with the European Green Deal and are promoted by the European Commission within the Farm-to-Fork-Strategy (Prache et al., 2022).

The perspectives of food science and technology place meat alternatives in the spotlight, providing industrial challenges in finding innovative technological solutions that provide new products with patent possibilities. In making meat alternatives, the components of food science and technology must be considered. Technological solutions will become extremely valuable in obtaining patents for protein alternatives, being awarded the most efficient and fertile technological potential and advantage to exploit (Tyndall et al., 2022). In this context, the review presents an in-depth documentation of artificial meat from different sources, the analysis of new directions in the food field, the materials and methods used, but also the perception of consumers regarding meat analogues.
CLASSIFICATION OF ARTIFICIAL MEAT

Food researchers are currently analysing two types of meat analogues: cultured meat (He et al., 2020; Hocquette, 2016; Bhat & Fayaz, 2011) and plant-based meat (He et al., 2020; Joshi & Kumar, 2015; Wild et al., 2014).

Recent developments in the field include other protein sources, for example microproteins (fermentation-based proteins) or microalgae extracted from Spirulina and proteins isolated from insects (Sha & Xiong, 2020).

Microalgae or microproteins, a new source of protein are proposed to be a promising ingredient for meat analogues. The protein content of microalgae can reach up to 71% depending on the species and the cultivation conditions. *Arthrospira* sp. (traded as Spirulina) and *Chlorella* sp., are the most traded microalgae on the market, their protein content exceeding 50% of the dry weight and even exceeding the typical 30-40% protein content of soybeans. Moreover, microalgae are a rich source of numerous nutrients and health beneficial components, including vitamins, minerals, proteins containing essential amino acids, polyunsaturated fatty acids, antioxidants, and dietary fibres (Bernaerts et al., 2019).

Furthermore, the yield of microalgae can reach 15-30 tons of dry biomass/unit area per year, while the yield of soybeans can reach only 1.5-3.0 tons/unit area per year (Fu et al., 2021).

There are companies dealing with the development of insects (mealworms, crickets, grasshoppers), with 2 million people from 130 countries consuming insects. The nutritional profile of insects shows that they are rich in protein (60% for crickets), fat, omega-3, minerals such as calcium, iron and vitamin B12 (Wood & Tavan, 2022). The edibility of insects indicates a high potential to become a major source of human nutrition that can be produced more efficiently than conventional animals, i.e. with lower levels of gas emissions and water consumption (Alexander et al., 2017).

In Europe the consumption of insect-based foods is relatively low, this is mainly due to social and contextual factors (House et al., 2016). Insects are environmentally friendly, nutritious alternatives rich in protein, zinc, iron, calcium and unsaturated fatty acids (Onwezen et al., 2019). The first insect-based product approved by the European Union for human consumption (using yellow mealworms) was granted in May 2021 (Wood & Tavan, 2022).

Agro-industrial waste can be used to produce human food through microbial fermentation. Various studies have reported the production of microprotein biomass using agro-industrial wastes (Ahmad et al., 2022).

Plant proteins have a well-balanced amino acid composition and excellent potential to replace meat by developing healthy meat-like products that are high in protein, low in saturated fat, cholesterol-free, and nutritionally similar (Sun et al., 2021). However, proteins from plant products are deficient in at least one of the essential amino acids, such as lysine, methionine and/or cysteine (Xie et al., 2022).

Cereal polysaccharides are an important source of dietary fibres with documented health implications in the eradication of convergent diseases. Studies have highlighted the exploitation of cereal polysaccharides in new food matrices, opening new horizons in the incorporation of cereal polysaccharides into meat products, as well as the influence of the functional characteristics of newly developed meat products. Their positive role as an antioxidant, antitumor, anti-inflammatory, antimicrobial agent has been proven by in vitro and in vivo chemical research (Kaur & Sharma, 2019).

Cultured meat is part of the emerging field of cellular agriculture and aims to produce products in the traditional way, by raising animals in new ways that require no or very little animal input. It is a promising technology (Figure 1) with key challenges and techniques, including cell source, culture media, mimicking animal derived in vivo myogenesis environment, and bioprocessing for industrial-scale production (Stephens et al., 2018).

Plant proteins are one of the key components for forming structure and nutritional value in meat analogues (Zhang et al., 2021). These can come from various plant sources such as soybeans, peas, beans, lentils, grains, algae and microalgae, etc., each with its own characteristics (McClements & Grossmann, 2021a; McClements & Grossmann, 2021b).

Meat analogues to obtain vegan meat come mainly from soy derivatives and fermented
products, as well as other sources (Mateti et al., 2022).

![Diagram of artificial meat categories](image)

**Figure 1. Classification of artificial meat**
(Source: Mateti et al., 2022)

The most representative meat analogues on the market are derived from vegetable proteins, from different nutritional, socioeconomic and technological considerations (Huang et al., 2022).

Soy is rich in carbohydrates, proteins, fats, fibres, vitamins, micro and macro nutrients (Ishaq et al., 2022). Soy protein has favourable gelling properties and functional properties: foaming, emulsifying, water and oil absorption and viscosifying ability. However, soy proteins also have limitations: undesirable grassy bean flavor, high allergenicity and methionine as a limiting amino acid (Lee, Choi, Han, 2022). Cereals (wheat, rice, barley, oats) are rich in carbohydrates, but have a lower protein content compared to soy. From a functional point of view, cereal proteins (especially wheat) are useful to producers of meat analogues because their structure gives consistency and texture like to meat products (Bohner, 2019). Mushrooms have a high protein content, being higher than that of wheat, comparable to that of animals or poultry, and close to that of soybean and pea proteins (Wang & Zhao, 2022). In meat analogues, the taste, aroma and color must be as close as possible to those of meat, and can be stimulated by adding spices, flavors, herbs and coloring agents (Flores & Piornos, 2021).

**MATERIALS, METHODS AND TECHNIQUES**

**Relevant studies on cultured meat technology**
The discovery of stem cells made it possible to produce cells in vitro, laying the theoretical foundations for cultured meat. Under special conditions of temperature, oxygen, nutrients and growth factors, stem cells can proliferate in vitro in the form of multinucleated myotubes, then through proliferation they pass into muscle fibres. Muscle fibres matures into muscle and can be processed into various products; roast beef, sausages, etc. The self-assembly technique can produce a three-dimensional cultured meat-like structure (Whang et al., 2021).

**Relevant technology studies for vegetable protein-based meat analogues** Various plant-based protein sources have been used to create meat analogues that mimic burgers, buns, sausages, etc. (Shaghaghian et al., 2022). Textured plant proteins are the most common ingredients in plant-based meat analogues. These are usually prepared from a mixture of soy protein, wheat gluten or pea protein by extrusion (Lin et al., 2022). Meat analogues often contain more than 20 ingredients: fats, sugars, vitamins, minerals, genetically modified pigments, phosphates, organic acids, etc. (Nagapo, 2022). These products are created using extrusion technology, but other methods can also be used (Shaghaghian et al., 2022).

Pressed soy cakes contain approximately 27% protein, 20% fat and 33% dietary fibres, but also a lot of anti-nutrients, which is the main reason why pressed soy cakes are not used directly as an ingredient in meat analogues. An effective strategy to decrease anti-nutrients may be solid fermentation with lactic acid bacteria, which could improve flavor and antioxidant activity. The effects of the applied processes on pressed soybean cakes, as well as the sensory properties of meat analogues, were analysed, the results obtained recommending the use of pressed soybean cake in meat analogues (Razavisageh et al., 2022). The wide variety of meat analogues has led some researchers to check whether the methods used to detect Salmonella are effective (Sampson et
Currently cell extrusion and shearing technologies have advanced, offering an optimal combination of scalability and efficiency in approaching structured proteins (Herz et al., 2021). The extrusion technology used in the manufacture of food products is carried out under the combined action of humidity, temperature, mechanical force, and pressure during the process, causing complex physico-chemical reactions: denaturation and aggregation of proteins, gelatinization and degradation of carbohydrates and inactivation of enzymes, microorganisms and anti-nutritional factors (Zhang et al., 2023). The effects of extrusion have been observed in various experiments, one of which aimed to improve the nutrients in meat analogues by using rice bran. In this case, the effects of extrusion aimed to analyse the following parameters: humidity, temperature and screw speed (Xiao et al., 2022). High humidity extrusion technology presents the following advantages: lack of waste, low costs, low energy consumption, versatility, efficiency and superior quality of textured products, representing an optimal choice for obtaining meat analogues with fibrous structures (Xia et al., 2022). Improving the texture and sensory properties of meat analogues developed from plants has become a priority for researchers, opening various research plans (Tibrewal et al., 2023). The new generation of plant-based textured meat analogues is trying to boost dietary fibres consumption. Another experimental study showed that oat fibres concentrate and pea protein isolate, combined in various proportions 30:70; 50:50; 70:30 and processed by high humidity extrusion (LCD cooling die long temperature: 40; 60; 80°C, screw speed 300; 400; 500 revolutions per minute) can be used to obtain fibrous meat analogues with textural properties similar to meat (Diaz et al., 2022). Instrumental techniques used to determine the structure of meat and meat analogues provide objective information on structural parameters in contrast to sensory analyses, which are time-consuming, expensive and difficult to do quantitatively. The study of the structure and texture of meat and meat analogues includes mechanical, spectroscopic and imaging characterization methods. The basic techniques and advances in meat processing technologies (beef, pork and poultry) and meat analogues (shear cell and extruded products) are represented in Table 1 (Schreureuters et al., 2021).

Table 1. Textural and structural methods used for meat (M, the color red) and meat analogues (MA, the color green). Abbreviations: NIR, Near-infrared; MIR, Mid-infrared; SAX(S)/S, Small-angle (X-ray) scattering; (SE)SANS, (Spin-echo) Small-angle neutron scattering; CLSM, Confocal laser scanning microscopy; SEM, Scanning electron microscopy; TEM, Transmission electron microscopy; AFM, Atomic force microscopy; MRI, Magnetic resonance imaging; XRT, X-ray tomography. Source: (Schreureuters et al., 2021)

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Researchers studied different compositions to develop plant-based meat alternatives, using pea protein and wheat protein in different ratios: 17:0; 13:4; 8.5:8.5; 4:13; 0:17 and using an innovative frozen structuring technique process. Following the experiment, the
physico-chemical and sensory properties of the analogues were analysed, showing that the analogue with a ratio of 4:13 (pea protein: wheat protein) was preferred, as it had a fibrous and layered structure. The incorporation of pea protein increased the hardness of the mixture as well as the viscoelastic properties of the analogues, the addition of wheat protein decreased the viscosity of the analogue. The ratio of vegetable proteins did not affect moisture (approx. 60%) and protein content (approx. 25%) of analogues. The experiment highlighted the potential of plant proteins in the development of plant-based analogues (Yuliarti et al., 2021). Many studies have been conducted to exploit the optimal processing conditions of meat analogues from vegetable proteins in high moisture extrusion technology (Wang et al., 2022; Dekkers et al., 2018). However, after extrusion, meat analogues based on plant proteins undergo secondary processing in which food additives (flavors, dyes) are added so that they possess meat-like properties (Wang et al., 2022). Raw materials such as soy and pea proteins can mimic the flavor, appearance and texture of traditional meats. The key problem with plant-based meat analogues is that pea proteins have an unpleasant bean-like flavor, mainly due to unsaturated fatty acids that hinder consumer acceptability. To remove the unpleasant flavor of beans, modern microbiologists use fermentation with the help of microorganisms, which also has other benefits such as restoring the intestinal microflora and repairing the damage to the intestinal epithelium caused by food additives (Tao et al., 2022).

Evidence shows that consumers’ emotional associations with food products can add additional information beyond general acceptance and even improve the prediction of food choice (Lagast et al., 2017). The SHART study helps researchers with two relevant questions:

a) What potential barriers might limit the adoption of plant-based beef and how might these barriers be removed?

b) If the obstacles are effectively addressed, then what is the probability that plant-based beef will replace beef?

SHART provides a structured methodology that researchers can use to transform historical knowledge into decision-makers, making a transition to a world with low greenhouse gas emissions (Roberts & Nemet, 2022). The perception of ecological sustainability and the factors that influence the consumer's desire to reduce meat consumption were analyzed in a study that addressed the following three questions:

a) Are consumers aware that eating meat leads to a large impact on the environment?

b) Are consumers willing to reduce meat consumption with an alternative?

c) Are consumers willing to accept meat substitutes and alternative proteins such as insects and cultured meat? (Hartmann & Siegrist, 2017).

The conclusions of the test revealed a very low level of consumers with reference to the awareness of the impact on the environment. Also, the desire to change meat consumption behaviour with meat substitutes or insect consumption is low. Regarding how consumers can be motivated to reduce meat consumption, their behaviour has been underexploited. One strategy (Figure 2) could be to find means and methods to motivate environmentally friendly meat-eating (Hartmann & Siegrist, 2017). Replacing traditional meat with plant-based and cultured meat analogues could solve the main environmental problem, namely reducing greenhouse gas emissions. The indirect benefit would be to design the production of meat analogues and cultured meat near the markets, avoiding the negative environmental effects due to transportation (Nezlek & Forestell, 2022).

FACTORS INFLUENCING CONSUMPTION OF ARTIFICIAL MEAT

The non-profit organization Good Food Institute, based in Washington D.C., reported that the overall market for plant-based foods in the United States was $7 billion in 2020, with an annual growth rate of 27% (Hu et al., 2022). In this context, there is a growing consensus that efforts to improve the sustainability of food systems will benefit from a transition towards an increased reliance on plant-based foods and a decrease in the consumption of meat and other animal products (Graça et al., 2019).
Some researchers question the assumption that the transition from eating animal meat to plant-based meat analogues and cultured meat will bring benefits (Nezlek & Forestell, 2022). Plant-based meat analogues are gaining increasing importance, meeting consumers’ desires for meat-like products and may facilitate future food supply (Jia et al., 2022). The choice to consume meat analogues is influenced by a number of factors (Pater et al., 2022). Despite the negative consequences of the global consumption of animal products, consumer choices regarding meat analogues are not primarily driven by arguments such as environmental impact or ethics. The main factors in choosing meat analogues are price, sensory quality, health, convenience (Bryant, 2022), environmental sustainability, animal welfare and familiarity with the product (Tyndall et al., 2022).

Consumer aversion to unfamiliar foods (food neophobia) and variety seeking are key factors in consumer acceptance of meat analogues. Research shows that although products may be initially rejected, repeated exposure can increase consumer acceptability (Gbejewoh et al., 2022).

Conducting a study that looked at meat products showed that 65% of reported findings had beneficial effects of meat extensions. Some extensions could be considered non-meat, and if well selected and properly added, based on bioactive, functional and technological properties can improve the nutritional value of consumers who serve meat products in their diet (Owusu-Ansah et al., 2022). Meat analogues have similar nutritional profiles to animal meat. However, the inclusion of a variety of additives to produce meat-like texture, juiciness, taste sensations and aroma, raises questions about the product’s nutritional value, food safety, labelling, cost and finally, consumer confidence (Ahmad et al., 2022).

Plant-based meat analogues are found in many vegetarian diets in developed countries. Climatic factors such as temperature and humidity can lead to the appearance of natural toxins (mycotoxins and plant alkaloids). Aflatoxins and ochratoxins are just two of the mycotoxins that can accumulate in grain, seed and bean crops. Pyrrolizidine and tropane are natural toxins synthesized in plants as secondary metabolites and can be found in legumes and seeds, contamination that may occur at harvest or during the production process (Mihalache et al., 2022).

The perception of meat analogues containing rapeseed protein was revealed in a cross-cultural study with 1397 consumers. The consumers were 100% women, the average age being 43 years, with secondary or higher education, married, engaged, from five European countries: Denmark, Finland, Germany, Iceland and Romania. As a result of the applied cross-cultural study, the following results emerged: consumers from Finland, Germany and Romania were open about the use of meat analogues, by using vegetable proteins as an ingredient; the study also showed that convincing Danish consumers to replace meat with meat analogues will not be an easy task (Banovic & Sveinsdottir, 2021).

To meet consumer needs, an important requirement is that meat analogues have a pronounced fibrous structure (Snel et al., 2021).

Addressing public health and environmental challenges points to possible solutions to replace meat with alternative sources: legumes, algae, alternative plant-based proteins, insects, cultured meat. Proteins from legumes and plants have the highest level of acceptability among consumers (Onwezen et al., 2021). A study on consumer perception of the
acceptability of protein sources was carried out on a sample of 1825 adults (from the United Kingdom of Great Britain), the Netherlands, Poland, Spain, Finland, the results showing that plant-based proteins were the most accepted (58%), followed by single-cell proteins (20%), insect-based proteins (9%) and in vitro meat-based proteins (6%) (Grasso et al., 2019). Particular attention should be paid to macronutrients such as sodium (Na) and potassium (K). Studies have reported that ground meat products of animal origin represent approximately 20-30% of the daily sodium (Na) requirement, while the value of sodium content in plant-based ground meat analogues is 6 times higher. The sodium content of fresh meat (before processing) is about 100 mg Na/100 g meat product of animal origin and for soy-based meat analogues it can reach 300 mg Na/100 g soy-based meat analogues product (Peng et al., 2023). To increase the acceptability of the consumption of plant-based meat analogues, an alternative is the consumption of hybrid products (50:50; combining meat with plant-based ingredients), at least in the transition phase. A cross-cultural study involving a sample of 2766 consumers in Denmark, Spain and the United Kingdom of Great Britain highlighted that hybrid products could represent an important factor in the acceptability of the transition from animal meat to plant-based meat analogues. The results of the study revealed that beef is preferred by consumers, with beans and oats being the main proteins accepted by consumers. In addition to beans and oats, peas, rapeseed, soy represent a sustainable and healthy source (Banovic et al., 2022).

Studies have shown that different cooking methods (mechanisms based on heat transfer) of meat analogues affect the quality of the product. During heating, the proteins denature and cause less water to be trapped inside the protein structures due to the evaporation of part of the water, therefore structural changes occur in meat and meat analogues, and tenderness is affected (Wen et al., 2022). The texture of meat analogues is correlated with moisture content (Jung et al., 2022).

Extrusion technologies are used to produce textured protein matrices for analogues, being divided into low-moisture cooking processes and high-moisture texturing processes. Low-moisture protein extrusion, developed in the 1960s, gives rise to expanded products or low-moisture meat analogues (25-30% w/w) (Ubbink & Muhialdin, 2022).

High-moisture extrusion processes started in the 1980s-1990s, and use cutting force in a specially developed texturing to obtain an anisotropic fibrous mass with high moisture, approximately 60% w/w (Ubbink & Muhialdin, 2022). The combination of high-moisture extrusion cooking combined with a shearing process during cooling is a new process for making fibrous products using meat analogues as an ingredient (Snel et al., 2021).

Rheology can be used to characterize mixtures of vegetable proteins (e.g., wheat, soy, peas) for their use in meat analogue applications (Schreuders et al., 2021), using the closed cavity rheometer (Dinani et al., 2023).

High humidity combined with a shearing process during cooling is a new process for making fibrous products using meat analogues as an ingredient (Snel et al., 2021). Understanding patent opportunities and finding innovative solutions will likely generate intellectual property rights for established meat analogues innovators. Food science and technology perspectives are becoming important to consumer acceptability of meat analogues solutions (Tyndall et al., 2022).

**CONCLUSIONS**

An alternative to the excessive consumption of meat of animal origin, which creates concerns related to public health, environment, ethics, ideology, can be analogues of meat and
cultured meat. The problem of environmental sustainability could be solved much more advantageously by the development of insects (mealworms, crickets, grasshoppers) or the production of microalgae, but so far there is a low acceptability on the side of consumers. Among the existing analogues on the market, meat analogues based on vegetable proteins are the most representative and the most accepted by consumers. Extrusion is the most used method to obtain plant-based meat analogues, but the sensory properties: taste, aroma, texture, tenderness of meat analogues must be like to animal meat to be accepted by consumers. Recent studies point to the exploitation and development of science in various research directions, such as analysing the benefits-risks of plant-based meat analogues production.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

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