AgroLife Scientific Journal - Volume 12, Number 1, 2023
ISSN 2285-5718; ISSN CD-ROM 2285-5726; ISSN ONLINE 2286-0126; ISSN-L 2285-5718

TRANSITION TO THE FUTURE: MEAT ANALOGUES & CULTURED MEAT

Adina NICHITA[1], Urszula TYLEWICZ[2], Mona Elena POPA[1]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest,
59 Mărăști Blvd, District 1, Bucharest, Romania
[2]University of Bologna, Piazza Goidanich 60, 47521, Cesena (FC), Italy

Corresponding author email: nichitaadina1979@gmail.com

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).

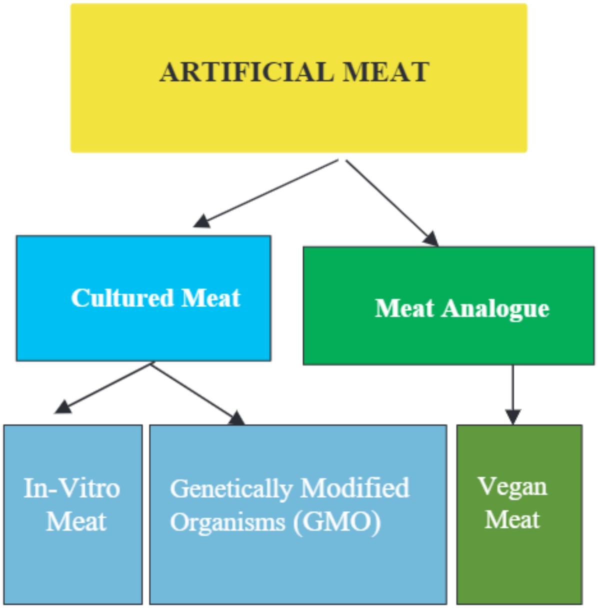

Figure 1. Classification of artificial meat
(Source: Mateti et al., 2022)

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 (Razavizageh 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

al., 2023). 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 (Schreureuders 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; SA(X)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: (Schreurders et al., 2021)

Texture and structure Mechanical	**Meat**	**Meat analogues**
Warner-Bratzler (Destructive)	X	X
Kramer Shear Cell (Destructive)	X	
Tensile (Destructive)	X	X
Compression & puncture (Destructive)	X	X
Texture Profile Analysis (Destructive)	X	X
Texture and structure Spectroscopy	**Meat**	**Meat analogues**
FTIR (Non-destructive)	X	X
NIR (Non-destructive)	X	
MIR (Non-destructive)	X	
Raman (Non-destructive)	X	
Fluorescence polarization (Non-destructive)	X	X
NMR (Non-destructive)	X	X
SA(X)S (Non-destructive)	X	
(SE)SANS (Non-destructive)	X	X
Light reflectance (Non-destructive)	X	X
Texture and structure Imaging	**Meat**	**Meat analogues**
Visual (Destructive)	X	X
CLSM (Destructive)	X	X
SEM (Destructive)	X	X
TEM (Destructive)	X	
AFM (Destructive)	X	X
MRI (Non-destructive)	X	
Ultrasound imaging (Non-destructive)	X	
Hyperspectral imaging (Non-destructive)	X	
XRT (Non-destructive)	X	X

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 epithetlium caused by food additives (Tao et al., 2022).

FACTORS INFLUENNCING CONSUMTION 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).

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).

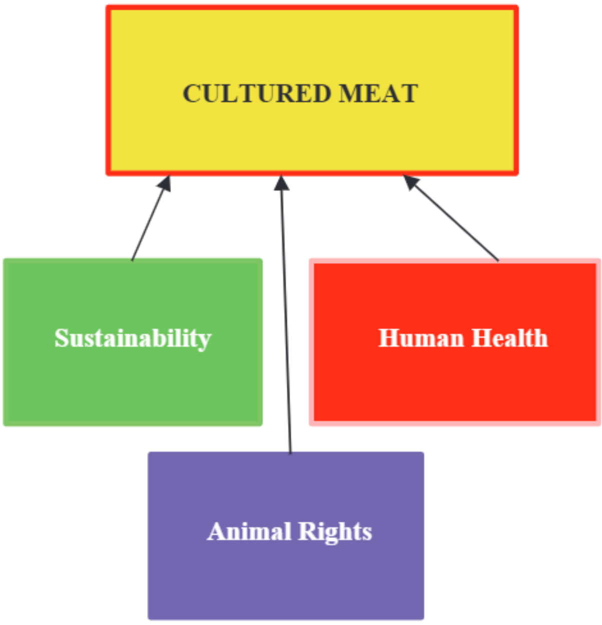

Figure 2. A concept to present cultured meat in the market (Source: Siddiqui et al., 2022)

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).

Plantain-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).

COOKING CHARACTERISTICS OF MEAT ANALOGUES

The traditional texturing process is extrusion (Tyndall et al., 2022). Both the low-moisture extrusion process and the high-moisture extrusion process can be used (Vatansever et al., 2020). The geometric factors, the product, the process variables, influence the physico-chemical transformations during the extrusion process. When it is desired to obtain a product with a fibrous structure, the extrusion process with high humidity, in a twin-screw extruder, is recommended (Tyndall 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 in 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, pea) 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 intertest.

ACKNOWLEDGEMENTS

I would like to thank the Doctoral School of Plant and Animal Resources Engineering and Management of the University of Agronomic Sciences and Veterinary Medicine in Bucharest, Biotechnology field, for the financial support that facilitated my participation in: The International Conference of the University of Agronomic Sciences and Veterinary Medicine of Bucharest, Romania, Agriculture for Life, Life for Agriculture.

REFERENCES

Ahmad, M. J., Qureshi, S., Akbar, M. H., Siddiqui, S. A., Gani, A., Mushtaq, M., Hassan, I., Dhull, S. B. (2022). Plant-based meat alternatives: Compositional analysis, current development and challenges. *Applied Food Research, 2,* 100154.

Ahmad, M. J., Farooq, S., Alhamoud, Y., Li, C., Zhang, H. (2022). Areview on mycoprotein: History, nutritional composition, production, methods, and health benefits. *Trends in Food Science & Technology, 121*, 14-29.

Alexander, P., Brown, C., Arneth, A., Dias, C. Finmigan, J., Moran, D., Rounsevell, M. D. A. (2017). Could consumption of insects, cultured meat or imitation meat reduce global agricultural land use? *Global Food Security, 15,* 22-32.

Banovic, M., Barone, A. M., Asioli, D., Grasso, S. (2022). Enabling sustainable plant-forward transition: European consumer attitudes and intention to buy hybrid products. *Food Quality and Preference, 96,* 104440.

Banovic, M., Sveinsdottir, K. (2021). Importance of being analogue: Female attitudes towards meat analogue containingra rapeseed protein. *Food Control, 123,* 107833.

Bernaerts, T. M. M., Gheysen, L., Foubert, I., Hendrckx, M. E., Loey, A. M. V. (2019). The potential of microalgae and their biopolymers as structuring ingredients in food. *Boitechnology Advances, 37,* 107419.

Bhat, Z. F., & Fayaz, H. (2011). Prospectus of cultured meatAdvancing met alternatives. *Journal of Food Sciences Technology, 48(2),* 125-140.

Bohrer, B. M. (2019). An investigation of the formulation and nutritional composition of modern meat analogue products. *Food Science and Human Wellness, 8,* 320-329.

Bryant, C. J. (2022). Plant-based animal product alternatives are healthier and more environmentally sustainable than animal products. *Future Food, 6,* 100174.

Craig, W. J., Mangels, A. R., Fresan, U., Marsh, K., Miles, F. L., Saunders, A. V., Haddad, E. H., Heskey, C. E., Johnston P., Larson-Meyer, E., Orlich, M. (2021). The safe and effective use of plant-based diets with guidelines for health professionals. *Nutrients, 13(11),* 4144.

Dekker, B. L., Boom, R. M., Van der Goot, A. J. (2018). Structuring processes for meat analogues. *Trends in Food Science & Technology, 81,* 25-36.

Diaz, J. M. R., Kantanen, K., Edelmann, J. M., Suhonen, H., Strohm, T. D., Jouppila, K., Piironen, V. (2022). Fibrous meat analogues containing oat fiber concentrate and pea protein isolate: Mechanical and physicochemical characterization. Innovative Food Science and Emerging Technologies.

Dinani, S. T., Boom, R., Jan var der Goot, A. (2023). Investigation potential of hydrocolloids in meat analogue preparation. *Food Hydrocolloids, 135*, 108199.

Estel, M., Huhghes, J., Grafenauer, S. (2021). Plant protein and plant-based meat alternatives: Consumer and nutrition professional attitudes and perception. *Sustainability, 13(3),* 1-18.

Flores, M., & Piornos, J. A. (2021). Fermented meat sausages and the challenge of ther plant-based alternatives: A comparative review on aroma -related aspects. *Meat Science, 183,* 108636.

Fu, Y., Chen, T., Chen, S. H. Y., Liu, B., Sun, P. Sun, H., Chen, F. (2021).The potentials and challenges of using microalgae as an ingredient to produce meat analogues. *Trends in Food Science & Technology*.

Gbejewoh, O., Marais, J., Erasmus, S. W. (2022). Planetary health and the promises of plant -based meat from a sub-Saharan African perspective; A review. *Scientific African, 17,* e01304.

Graça, J., Godihno, C. A., Truninger, M. (2019). Reducing meat and following plant-based diets: Current evidence and future directions to inform

integrated transitions. *Trends in Food Science &Technology, 91,* 380390.
Grasso, A. C., Hung, Y., Olthof, M. R., Verbecje, W., Brouwer, I. A. (2019). Older Consumers Readiness to Accept Alternative, More Sustenable Proteine Surcesin the Europen Union. *Nutrients, 11,* 1904.
Hartmann, C., Siegrist, M. (2017). Consumer perception and behaviour regarding sustenable protein consumtion: A systematic review. *Trends in Food &Technology, 61,* 11-25.
Hassoun, A., Boukid, F., Pasqualone, A., Bryant, C. J., Garcia, G., Para-Lopez, C., Jagtap, S., Trollman, H., Cropotova, J., Barba, F. J. (2022). Emerging trendsin the agri-food sector: Digitalisation and shift to plant-based diets. *Current Research in Food Science, 5,* 2261-2269.
He, J., Evans, N. M., Shao, S., Liu, H. (2020). A review of research on plants-based meat alternatives: Driving, forces, history, manufacturing. And consumer attitudes. *Comprehensive Review in food Sciences and Food Safety, 19:* 2639-2656.
Herz, E., Herz, L., Dreher, J., Gibis, M., Ray, J., Pibarot, P., Schmitt, C., Weiss, J. (2021). Influenciting factors on the ability to assemble a complex meat analogue using a soy -protein-binder. *Innovative Food Science and Emerging Technologies, 63,* 102806.
Hocquettem J. F. (2016). Is *in vitro* meat the solution for the future? *Meat Sciences, 120,* 167-175.
House, J. (2016). Consumer acceptance of insects-based food in the Metherlands: Academic and commercial implication. *Appetite, 106,* 47-58.
Huang, M., Mehany, T., Xie, W., Liu, X., Guo, S., Peng, X. (2022). Use of food carcohydrates towards the innovation of plant-based. *Trends in Food Science &Technology, 129,* 155-163.
Hu, X., Zhou, H., McClements, D. J. (2022). Utilization of emulsion technology to create plant-based adipose tissueanalogs: Soy-based high internal phase emultion. *Food Structure, 33,* 100290.
Ishaq, A., Shafeeqa, I., Sameen, A., Khalid, N. (2022). Plantbased meat analogs: A review with reference to formulation and gastrointestinal fate. *Current Research in Food Science, 5,* 973-983.
Jia, W., Sutanto, I. R., Ndiaye, M., Keppler, J. K., Jan van der Goot, A. (2022). Effect of aqueours ethanol washing on functional proprieties of sunflower materials for meat analogue application. *Food Structure, 33,* 100274.
Joshi, V., & Kumar, S. (2015). Meat Analogues. Plant based alternatives to meat products-A review. *International Journal of Food Fermentation Technology, 5(2),* 107.
Jung, A. H., Hwang, J. H., Jun, S., Park, S. H. (2022). Application of ohmic cooking to produce a soy protein-based. *LWT-Food Science and Technology, 160,* 113271.
Kaur, R., Sharma, M. (2019). Cereal polysaccharides as source of functional ingredient for reformulation of meat products: A review. *Journal of Functional Food, 62,* 103527.
Kazir, M., & Livney, Y. D. (2001). Plant-Based Seafood Analogs. *Molecules, 26,* 1559.
Lagast, S., Gellynck, X., Schouteten, J. J., De Herdt, V., De Steur, H. (2017). Conssumers emotions elicited by food: A systematic reciew of explicit and implicit methods. *Trends in Food Science & Technology, 69,* 172189.
Lai, W. T., Khong, N. M. H., Lim, S. S., Hee, Y. Y., Sim, B. I., Lau, K. I., Lai, O. M. (2017). A review: Modified agricultural by-products for the development and fortification of food products and nutraceuticals. *Trends in Food Sciences &Technology, 59,* 148-160.
Lee, H. J., Yong, H. I., Kim, M., Choi, Y. S., Jo, C. (2020). Status of meat alternatives and their potential role in the future meat market: a review. *Asian-Australasian Journal of Animal Sciences, 33(10),* 15331543.
Lee, J. S., Choi, I., Han, J. (2022). Construction of rice protein -based meat analogues by extruding process: Effect of substitution of soy protein with rice protein on dynamic energy, appearance, physicolhemical, and textural properties of meat analogues. *Food Research International, 161,* 111840.
Lima, M., Costa, R., Rodrigues, L., Lameiras, L., Botelho, G. (2022). A Narrative Review of Alternative Protein Surces: Highlights on Meat, Fish, Egg and Dairy Analogues. *Food, 11,* 2053.
Lin, Q., Pan, L., Deng, N., Sang, M., Cai, K., Chen, C. (2022). Protein digestibility of textured-wheat-protein (TWP)based meat analogues: (I) Effects of fibrous structure. *Food Hydrocolloids, 130,* 107694.
Mateti, T., Laha, A., Shenoy, P. (2022). Artificial Meat Industry: Production Methodology, Challehges, and Future. *Interactions Between Biomaterials and Biological Tissues and Cells,* Vol. 74, No. 9.
McClements, D. J., Grossmann, L. (2021a). A brief review of the science behind the design of healthy and sustainable plant-based food. *Npj Sciences of Food, 5.*
McClements, D. J., Grossmann, L. (2021b). The sciences of plant-based food: Constructing nex-generation meat, fish, milk, and egg analogs. *Comprehensive Review in Food Sciences and Food Safety, 20,* 40494100.
Mihalache, O. A., Delllafiora, L., Dal Asta, C. (2022). Riskbenefit assessment of shifting from traditional meatbased diets to alternative dietary patterns. *EU-FOR A EFSA Journal 2022, 209(S2)*: e200919.
Nagapom, T. M. (2022). Meat analogues, the Canadian Meat Industry and the Canadian consumer. *Meat Science, 191,* 108846.
Nezlek, J. B., Forestell, C. A. (2022). Meat substitutes:current status, potential benefits, and remaining challenges. *Current Opinion in Food Science, 47:* 100890.
Onwezen, M. C., Brouwman, E. P., Reinders, M. J., Dagevos, H. (2021). A systematic review on consumer acceptance of alternative proteins: Pulses, algae, insects, plant-based meat alternatives, and cultured meat.
Onwezen, M. C., Van der Puttelaar, J., Verain, M. C. D., Veldkamp, T. (2019). Consumer acceptance of insect as foiod and feed: Th relevance of affective factors. *Food Quality and Preference, 77,* 51-63.

Owusu-Ansah, P., Besiwah, E. K., Bonah, E., Amagloh, F. K. (2022). Non-meat ingredients in meat products: A scoping review. *Applied Food Research, 2,* 100044.

Pater, L., Kollen, C., Damen, F. W. M., Zandstra, E. H., Fogliano, V., Steenbekkers, B. L. P. A. (2022). The perception of 8-10 yer-old Dutch children towards plant-based meat analogues. *Appetite, 178 (1022),* 106264.

Razavizadeh, S., Alencikiene, G., Vaiciulyte-Funk, L., Erbjerg, P., Salasevicien (2022). Utilization of fermented and enzymatically hydrolyzed soy press cake as ingredient for meat analogues. *LWT-Food Science and Technology, 165,* 113736.

Robert, C., Nemet, G. (2022). Systematic Historical Analogue Research for Decision-macking (SHARD): Introducing a new methology for using historical case studies to informlow-carbon transitions. *Energy Research & Social Science, 93,* 102768.

Prache, S., Adamiec, C., Astruc, T., Baeza-Campone, E., Bouillot, P. E., Clinquart, A., Feidt, C., Fourat, E., Gautron, J., Girard, A., Guillier, L., Kesse-Guyot, E., Lebret, B., Lefevre, F., Le Perchec, S., Martin, B., Mirade, P. S., Pierre, F., Raulet, M., Remond, D., Sans, P., Souchon, I., Donnars, C., Sante-Lhoutellier, V. (2022). Review: Quality of animal-source food. *Animal, 16,* 100376.

Peng, Y., Ahao, D., Li, M., Wen, X., Ni, Y. (2023). Production and functional characteristics of low-sodium highporassium soy protein for the development of healthy soy-based foods. *International Journal of Biological Macromolecules, 226,* 1332-1340.

Sampson, G. L., Ruelle, S. B., Phan, L., Williams-Hill, D., Hellberg, R. S. (2023). Effectinessof selected preenrichment broths for the detection of Salmonella spp, in meat analogs. *Food Control, 143,* 109282.

Samtya, M., Aluko, R. E., Dhewa, T., Moreno-Rojas, J. M. (2021). Potential health benefits of plant food-derived bioactive components: an overview. *Food, 10 (4),* 839.

Schreuders, F. K. G., Sagis, L. M. C., Bodnar, I., Erni, P., Boom, R. M., Jan var der Goot, A. (2022). Mapping the texture of plantprotein blends for meat analogues. *Food Hydrocolloids, 118 (2021),* 106753.

Schreuders, F. K. G., Schlangen, M., Kyriakopoulou, K., Boom, R. M., Jan van der Goot, A. (2021). Texture methods for evaluating meat and meat amalogue structures: A review. *Food Control, 127,* 108103.

Sha, L., Xiong, Y. L. (2020). Plant protein-based alternatives of reconstructed meat: Science, technology, and challenges. *Trends in Food Science & Technology.*

Shaghaghian, S., McClemente, D. J., Khalesi, M., GarciaVaquero, M., Mirzapour-Kouhdasht, A. (2022). Digestibility and bioavailability af plant-based proteins intended for use in meat analogues: A review. *Trends in Food Science &Technology, 129,* 64665 6.

Siddiqui, S. A. Bahmid, N. A., Karim, I., Melany, T. Gvozdenko, A. A., Blinov, A. V., Nagdalian, A. A., Arsyad, M., Lorenzo, J. M. (2022). Cultured meat: Processing, packaging, shelf life, and consumer acceptance. *LWT-Food Science and Technology, 172,* 114192.

Smel, S. J. E., Bellwald, Y., Jan van der Goot, A., Michael, B. (2022). Novel rotating die coupled to a twin -screw extruder as a new route to produce meat analogues with soy and gluten. *Innovative Food Science and Emerging Technologies, 81,* 103152.

Stephens, N., Di Silvo, L., Dunsford, I., Ellis, M., Glencross, A., Sexton, A. (2018). Bringing cultured neat to market: Technical, socio-political, and regulatory challenges in cellular agriculture. *Trends in Food Science & Technology, 78,* 155-166.

Sun, C., Ge, J., He, J., Gan R. Fang, Y. (2021). Processing, Qualoty, Safety, and Acceptance of Meat Analogue Products. *Engineering, 7,* 674-678.

Szpicer, A., Onopiuk, A., Barczak, M., Kurek, M. (2022). The optimization of a gluten-free and soy-free plantbased meat analogue recipe enriched with anthocyanins microcapsules. *LWT-Food Sciences and Technology, 168,* 113849.

Tao, A., Zhang, H., Duan, J., Xiao, Y., Liu, Y. M., Li, J., Huang, J., Zhong, T., Yu, X. (2022). Mechanism and application of fermentation to remove beany flavor from plant based meat analogs: A mini review. *Frontiers in Microbiology, 13:* 1070773.

Tibrewal, K., Dandekar, P., Jain, R. (2023). Extrusion-based sustainable 3D bioprinting of eat & its analogues: review. *Bioprinting, 29,* e00256.

Tyndall, S. M., Maloney, G. R., Cole, M. B., Hazell, N. G., Augustin, M. A. (2022). Critical fod and nutritionscience challenges for plant-based meat alternative products. *Critical Review in Food Science and Nutrition, DOI:10.1080/10408398.2022.2107994.*

Ubbink, J., Muhialdin, B. J. (2022). Protein physical state in meat analogue processing. *Current Opinion in Food Science 2022, 45:* 100822.

Vatansever, S., Tulbek, M. C., Riaz, M. N. (2020). Low-andhigh-moisture extrusion of pulse proteins as plantbased meat ingredients: Areview. *Cereal Food World, 65(4)*: 38.

Wang, L., Xu, J., Zhang, M., Zheng, H., Li, L. (2022). Preservation of soy protein -based meat analogues by using PLA/PBAT antimicrobial packaging film. *Food Chemistry, 380,* 132022.

Wang, M., Zhao, R. (2022). A review on nutritional advantages of edible mushrooms and its industrialization development situation in protein meat analogues. *Journal of Future Foods, 3-1 (2023),* 1-7.

Wang, Y., Pulkkinen, M., Edelmann, M., Katina, K., Tuccillo, F., Kariluoto, S., Jouppila, K., Lampi, A. M., Coda, R., Sandell, M., Kanaapila, A., Piironen, V. (2022). Flavor challenges in extruded plant-based meat alternatives: A review. *Comprehensive Review in Food Sciences and Food Safety, 21,* 2898-2929.

Wen, Y., Kim, H. W., Park, J. H. (2022). Effects of transglutaminase and cooking method on the physicochemical characteristics of 3D-printable meat analogs. *Innovative Food Science and Emerging Technologies.*

Wild, F., Czerny, M., Janssen, A. M., Kolle, A. P., Zunabovic, M., Domig, K. J. (2014). The evolution of a plant-based alternative to meat. From niche markers to widely accepted meat alternatives. *Agro Food Industry Hi Teach, 25(1),* 45-49.

Wood, P., Tavan, M. (2022). A review of the alternative protein industry. *Current Opinion in Food Science, 47*: 100869.

Xia, S., Xue, Y., Xue, C., Jiang, X., Li, J. (2022). Structural and rheological properties of meat analogues from Haematococcus pluvialis residue-pea protein by moisture extrusion. *LWT-Food Science and Technology, 154,* 112756.

Xiao, Z., Jiang, R., Huo, J., Wang, H., Li, H., Su, S., Gao, Y., Duan, Y. (2022). Rice bran meat analogs: Relationship between extrusion parameters, apparent properties and secondary structures. *LWT-Food Science and Technology, 163,* 113535.

Xie, Y., Cai, L., Zhao, D., Liu, H., Xu, X., Zhou, G., Li, C. (2022). Real meat and plant-based meat analogues have different in vitro protein digestibility properties. *Food Chemistry, 387(2922),* 132917.

Yuliarti, O., Kovis, T. J. K., Yi, N. J. (2021). Structuring the meat analogue by using plant-based derived composites. *Journal of Food Engineering, 288,* 110138.

Zhang, L., Hu, Y., Badar, I. H., Xia, X., Kong, B., Chen, Q. (2021). Prospects of artificial meat: Opportunities and challenges around consumer acceptance. *Trends in Food Science & Technology, 116*, 434-444.

Zhang, Y., He, Z., Xu, M., Zhang, X., Cao, S., Hu, Y., Luan, G. (2023). Physicochemical pro perties and protein structure of extruded corn gluten meal: Implication of temperature. *Food Chemistry, 399,* 133985.

Zhou, H., Hu, Y., Tan, Y., Zhang, W., Mc Clements, D. J. (2021). Digestibility and gastrointestinal fate of neat versus plant-based meat analogs: An in vitro comparison. *Food Chemistry, 364,* 130439.

Zioga, E., Tostesen, M., Madsen, S. K., Shetty, R., Bang Berthelsen, C. H. (2022). Bringing plant-based Cli-meat closer to original meat experience: insights in flavor. *Future Foods, 5,* 100138.