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THE CHALLENGES AND ALTERNATIVES OF FOOD SUSTAINABILITY: MEAT ANALOGUES & CULTURED MEAT

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Abstract

The present paper is based on a bibliographic study of over 100 articles published between 2001 and 2023 with general aim of the identification of the most causes that led to the need to replace meat of animal origin with meat analogues and/or cultured meat. The identification of new protein sources and the characterization of the nutritional profile, textural behaviour, sensorial attributes, etc. of meat analogues open new research horizons. The review of the most relevant studies on how to obtain plant-based meat analogues brings to the attention of researchers various pretreatments such as extrusion, hydrogenation, hydrolysis, as well as other technological challenges in improving the quality of plant-based meat analogues. Current research on the new food products development highlights the need regarding the risks and benefits analysis of plant-based and cultured meat analogues, which require in-depth studies in many directions.

Key words*: food sustainability, meat analogues, cultured meat, processing methods.*

INTRODUCTION

The food sector represents approximately 26% of global greenhouse gas emissions (Zioga et al., 2022). Concerns about the health of the planet are increasingly prominent meat alternatives being a potential alternative (Gbejewoh et al., 2022).

The harmful effects of animal production led to the development of technologies and the need to find alternatives, such as vegetable proteins (Szpicer et al., 2022; Estel et al., 2021; Lai et al., 2017). These are textured food products made from plant-derived proteins that mimic or replace meat (Wang et al., 2022; Lee et al., 2020).

The aim of these analogues is to imitate the physical and organoleptic properties of animal products through the fibrous composition and the mixture of ingredients from plant sources, using appropriate technology, which allows providing a similar texture and flavors. (Lima et al., 2022).

The demand for innovative meat analogs is a relevant issue in the food sector (Szpicer et. al., 2022), the perspectives of food science and technology providing industrial challenges in identifying innovative technological solutions is the one that provide new products with patent possibilities (Tyndall et al., 2022). Innovative technologies and alternative protein sources have been associated with sustainable food systems as well as improved nutritional quality and safety of the food products (Hassoun et al., 2022).

For humanitarian reasons, vegans and vegetarians avoid animal products and enjoy the nutritional benefits by using alternative foods (Kazir & Livney, 2021). Plant-based diets are beneficial for health due to reduced risk of obesity, tumors and cardiovascular diseases (Hassoun A. et al., 2022; Craig et al., 2021; Samtya et al., 2021), these changes being promoted by the Commission European within the Farm-to-Fork-Strategy (Prache et al., 2022).

In this context, this review provides an in-depth documentation of the characteristics of artificial meat from different sources, analyzes current trends, materials and methods used, and consumer perception of meat analogs.

CLASSIFICATION OF ARTIFICIAL MEAT

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

Meat alternatives can be classified in turn: plant-based (soy, pea, gluten, etc.), cell-based (*in vitro* or cultured meat) and fermentation-based (microproteins or microalgae extracted from Spirulina and isolated proteins from insects), the figure (Figure 1) presented below highlighting the concept of artificial meat classification (Sha & Xiong, 2020).

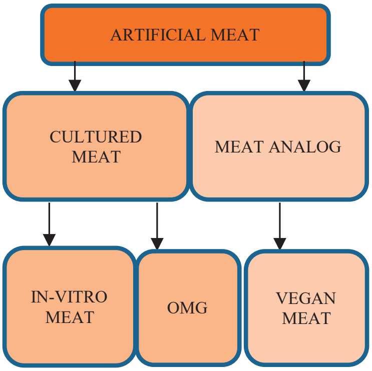

Figure 1. Classification of artificial meat *(in vitro* meat, OMG-genetically modified organisms, vegan meat)
Source: (Mateti et al., 2022)

CHARACTERIZATION OF ARTIFICIAL MEAT SOURCES

The representative meat alternatives on the market are analogs derived from vegetable proteins, for various socio-economic, nutritional and technological considerations (Huang et al., 2022). A transition from animal to vegetal proteins would be beneficial for biodiversity, land use, water use, climate, and people, also for animal health and welfare (Hartmann et al., 2017; Aiking et al., 2011; Leip et al., 2015). Plant proteins mixture may have a well-balanced amino acid composition and excellent potential to replace meat by developing healthy meat-like and nutritionally similar products (Sun et al., 2021).

One of the key components for the formation of the structure and nutritional value of meat analogs is plant proteins (Zhang et al., 2021), which can come from various plant sources such as soybeans, peas, beans, lentils, cereals, algae and microalgae, etc., each possessing its own characteristics (McClements & Grossmann, 2021a; McClements & Grossmann, 2021b). However, proteins from plant products are deficient in at least one of the essential amino acids, such as lysine, methionine, or cysteine (Xie et al., 2022). Meat analogs used to obtain vegan meat mainly come from soybean derivatives rich in carbohydrates, proteins, fats, fibers, vitamins, micro and macronutrients (Ishaq et al., 2022), fermented products, etc., (Mateti et al., 2022). Although soy protein has good functional properties in terms of appearance, texture, structure and taste (such as emulsification, foaming, water and oil absorption, viscosification ability and gelation), it also has limitations such as undesirable grassy bean flavor, high allergenicity and methionine as a limiting amino acid (Lee, Choi, Han, 2022). Compared to soy, cereals (wheat, rice, barley and oats) are rich in carbohydrates and have a lower protein content, and from a functional point of view, the structure of wheat proteins gives consistency and texture similar to meat products (Bohrer, 2019).

Mushrooms have a high protein content, comparable to that of animals or poultry, close to that of soybean and pea protein, and higher than that of wheat (Wang & Zhao, 2022). In the case of meat analogs, the organoleptic properties must be as close as possible to those of meat, and can be stimulated by adding mineral and vegetable spices, food colorings, etc. (Flores & Piornos, 2021).

The first insect-based product approved by the European Union for human consumption (using yellow mealworms) was granted in May 2021 (Wood & Tavan M, 2022), however the consumption of insect-based foods in Europe is relatively low, due to social and contextual factors (House et al., 2016). The nutritional profile of insects (mealworms, crickets, grasshoppers), shows that they are rich in protein (60% for crickets), fats, minerals and vitamins (Wood & Tavan, 2022), their edibility representing a high potential to become a major source of human nutrition that can be produced more efficiently (with lower levels of gas emissions and water consumption) than conventional animals, (Alexander et al., 2017; Onwezen et al., 2019).

Microalgae or microproteins are a rich source of numerous nutrients and components beneficial to health, including vitamins, minerals, proteins containing essential amino acids, polyunsaturated fatty acids, antioxidants and dietary fiber (Bernaerts et al., 2019). The yield of microalgae can reach between 15-30 tons of dry biomass/area unit per year, while soybean yield can reach 1.5-3.0 tons/area unit per year (Fu et al., 2021).

Various studies have indicated the production of microprotein biomass using agro-industrial wastes such as industrial peas and pineapple peas (Ahmad et al., 2022).

Cereal polysaccharides are an important source of dietary fiber, studies highlighting their exploitation in different food matrices. Their positive role as an antioxidant, antitumor, anti-inflammatory, antimicrobial agent being proven by in vitro and in vivo chemical research (Kaur & Sharma, 2019)

Cultured meat is part of the field of cell agriculture, a promising technology with key challenges and techniques including cell source, culture medium, mimicking animal-derived in vivo myogenesis medium, and bioprocessing for industrial-scale production (Stephens et al., 2018).

MATERIALS, METHODS AND TECHNIQUES

Relevant technology studies for vegetable protein-based meat analogues & cultured meat

The new generation of plant-based textured meat analogs is trying to boost dietary fiber consumption. (Diaz et al., 2022). Meat analogs usually contain more than 20 ingredients: fats, sugars, vitamins, minerals, genetically modified pigments, phosphates, organic acids, etc. (Nagapo, 2022). These products are obtained using extrusion technology or other methods (Shaghaghian et al., 2022). Textured plant proteins are the most common ingredients in plant-based meat analogs (Lin et al., 2022). Pea proteins have an unpleasant flavor similar to beans, and to eliminate it, modern microbiologists use fermentation with the help of microorganisms, which also has other benefits such as restoring the intestinal microflora and repairing damage to the intestinal epithelium caused by food additives (Tao et al., 2022). Soy cakes contain proteins, fats, dietary fibers, but also a lot of anti-nutrients. The reduction of antinutrients is achieved by solid state fermentation with lactic acid bacteria, the results obtained, as well as the sensory properties of the meat analogues obtained, recommend them for the use of pressed soybean cake in meat analogues (Razavizadeh et al., 2022). Structuring methods such as cell extrusion and shearing techniques have been widely studied (He et. al., 2020). Currently cell extrusion and shearing technologies have advanced, providing an optimal combination of scalability and efficiency in the approach to structured proteins (Herz et al., 2021). During extrusion, complex physicochemical reactions occur such as denaturation and aggregation of proteins, gelatinization and degradation of carbohydrates, inactivation of enzymes, microorganisms and antinutritional factors (Zhang et al., 2023). Various studies have exploited the optimal processing conditions of vegetable protein meat analogs in high moisture extrusion technology (Wang et al., 2022; Dekker et al., 2018). A lot of experiments have shown that high moisture extrusion technology presents multiple advantages: lack of waste, low costs, low energy consumption, efficiency, versatility and superior quality of textured products, representing an optimal choice for obtaining meat analogues with fibrous structures (Xia et al., 2022). Improving the sensory properties of plant-based meat analogues opens new research horizons (Tibrewal et al., 2023). The study of the structure and texture of meat and meat analogues includes mechanical, spectroscopic and imaging characterization methods (Schreuders et al., 2021) as shown in the table below (Table 1).

Table 1. Textural and structural methods used for meat (M, the color red) and meat analogues (MA, the color green)

Texture and structure Mechanical	**Meat**	**Meat analogues**
Warner-Bratzler (Distructive)	X	X
Kramer Shear Cell (Distructive)	X	
Tensile (Distructive)	X	X
Compression & puncture (Distructive)	X	X
Texture Profile Analysis (Distructive)	X	X
Texture and structure Spectroscopy	**Meat**	**Meat analogues**
FTIR (Non-destructive)	X	X
NIR (Non-destructive)	X	
MIR (Non-destructive)	X	
Raman	X	
(Non-destructive)		
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 (Nondestructive)	X	X
Texture and structure Imaging	**Meat**	**Meat analogues**
Visual (Distructive)	X	X
CLSM (Distructive)	X	X
SEM (Distructive)	X	X
TEM (Distructive)	X	
AFM (Distructive)	X	X
MRI (Non-destructive)	X	
Ultra sound imaging (Non-destructive)	X	
Hyperspectral imaging (Non-destructive)	X	
XRT (Non-destructive)	X	X

Abbreviations: NIR, Near-infrared; MIR, Mid- infrared; NMR- Nuclear Magnetic Resonance Spectroscopy; 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: (Schreuders et al., 2021).

The researchers studied different compositions to develop plant-based meat analogues, using pea protein and wheat protein in different proportions. The experiment highlighted the potential of plant proteins in the development of plant-based analogues (Yuliarti et al., 2021). After extrusion technology, meat analogs based on vegetable proteins are subjected to secondary processing in which food additives (flavors, dyes) are added to the composition to that they possess meat-like sensory properties (Wang 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). In order to btain cultured flesh there are two main methods of propagation in vitro: propagation from axillary or terminal buds and propagation by the formation of adventitious shoots or somatic embryos (Goncalves et al., 2013).

TRENDS AND PERSPECTIVES

The meat market is restricted by population growth (Thomson, 2003), animal diseases (Bonny et al., 2015), environmental problems (Aiking, 2011; Nemecek et al, 2016;), potential risks of disease such as diabetes, obesity, cardiovascular diseases (Larsson & Wolk, 2010; Mehta et al., 2015; Rohrmann et al.,2013) and production costs (Pimentel & Pimentel, 2003; Smetana et al., 2015), which inspires a tendency to find suitable meat substitutes (Xiao et al., 2022).

The transition from eating meat and other animal products to plant-based products such as meat analogs is supported by the research community (Banovic et al., 2021; Aiking et al., 2018; Bryant et al., 2019; Graça et al., 2019; He et al., 2020), because these products have the potential to meet both the nutritional needs of the population (Banovic et al., 2021; Bohrer, 2019), as well as decreasing the negative impact of food production on the environment ((Banovic et al., 2021; Kyriakopoulou et al., 2019). The transition from animal products to ecological alternatives can be achieved when consumer acceptance of herbal alternatives is high (Zhang et al., 2023).

The non-profit organization Good Food Institute reported that the total plant-based food market in the United States has grown by 27% (Hu, et al., 2022). Replacing traditional meat with plant-based and cultured meat analogues could solve the main environmental problem, namely the reduction of greenhouse gas emissions (Nezlek & Forestell, 2022). Efforts to improve the sustainability of food systems 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). Vegetarians, vegans and flexitarians have a high ethical conscience and are the main consumers of meat analogs; consisting of 78.1% vegan, 32% vegetarian, 37.1% high/added protein and 31.3% gluten-free (Ishaq et al, 2022). In order to stimulate the transition from meat consumption to plant-based meat alternatives, studies show that the textural and sensory properties of meat analogues should be improved (Dinani et al., 2023; Grossmann & McClements, 2021; Hoek et al., 2011; Michel et al., 2021).

Meat analogs have similar nutritional profiles to animal meat (Ahmad et al., 2022) and are found in many vegetarian diets in developed countries. (Mihalache et al., 2022). Proteins from legumes and plants have the highest level of acceptability among consumers (Onwezen et al., 2021), beans, oats, peas, rapeseed, soy, etc. representing a sustainable and healthy source (Banovic et al., 2022). One of the critical aspects of plant-based meat analogue development is the selection of appropriate protein supply. It is listed that mixing wheat gluten with soy protein produced a meat analog with physical properties like animal meat (Mishal et al., 2022; Chiang et al. 2019).

Plantain-based meat analogs are becoming increasingly important, satisfying consumers' desires for meat-like products (Jia et al., 2022). Among plant-based foods, soy protein isolate is a popular ingredient due to its relatively low price and versatile properties (Peng et al., 2023). Soy protein is an excellent substitute for animal protein, which has been widely used since the 1990s due to its characteristic gelling property and ability to fabricate anisotropic fiber structure (Zhang et al., 2021; Day et al., 2013; Lan et al., 2020). Soybean protein textured with beetroot juice (obtained from fresh beetroot, cooked beetroot, beetroot powder and commercial beetroot juice) showed the same appearance as beef and pork, respectively, which is consistent with their hue values and reflectance spectra. The attractive red color of betalains and their stability at the pH value of meat analogs make beetroot juices ideal for their application as colorants in meat analogs (Fernandez-Lopez et al., 2023). Color and color variations significantly influence the quality of meat analogs (Ishaq et al., 2022).

The choice to consume meat analogs is influenced by a number of factors (Pater et al., 2022) such as price, sensory quality, health, convenience (Bryant, 2022), environmental sustainability, animal welfare (Tyndall et al., 2022) and by consumers' emotional associations with food products that can even improve the prediction of food choice (Lagast et al., 2017). One of the problems of cultured meat is the absence of myoglobin in the composition, which is responsible for the red color of meat of animal origin. To solve this problem, the following can be used in the cultured meat production process: natural dyes (sugar beet or saffron), hemoglobin isolated from the animal's blood or its derivatives (Siddiqui et al., 2022; Mateti, Laha and Shenoy, 2022).

COOKING CHARACTERISTICS OF MEAT ANALOGUES

The traditional texturing process is extrusion (Tyndall et al., 2022), and both low moisture and high moisture extrusion processes can be used (Vatansever et al., 2020). High-moisture extrusion originated in the 1980s-1990s, and low-moisture protein extrusion developed in the 1960s, giving rise to expanded products or low-moisture meat analogs (Ubbink & Muhialdin, 2022). High-moisture extrusion cooking with a novel rotary die was experimentally performed using a Clextral Evolum 25 twin-screw extruder (Clextral, Firminy, France). The extruder having a screw diameter of 25 mm and a length/diameter ratio of 40 (Snel et al., 2022). Studies have shown that different cooking methods (thermal treatments based on heat transfer) of meat analogues affect tenderness and also changes in the structure of meat analogues (Wen et al., 2022). The texture of meat analogs is correlated with moisture content (Jung et al., 2022). Rheology can be used to characterize plant protein mixtures (wheat, soy, pea) used in meat analog applications (Schreuders et al., 2021), using the closed cavity rheometer (Dinani et al., 2023).

CONFLICT OF INTEREST

Both authors declare no conflict of intertest.

CONCLUSIONS

The excessive consumption of meat of animal origin creates environmental, ethical, ideological and last but not least public health concerns. An alternative to environmental sustainability could be the analogs of meat and cultured meat. Among existing analogs, plant-based meat analogs are the most representative with high consumer acceptability.

The main sources of plant-based proteins used for the production of meat analogues are legumes (soy, peas, lentils, chickpeas), pseudocereals (buckwheat), cereals (wheat, rice), tubers (potatoes), seeds and nuts (Kazir et al., 2021).

Extrusion is the most widely used method for obtaining plant-based meat analogues. The problem of environmental sustainability could be solved much more advantageously by breeding and developing insects, mealworms, crickets, grasshoppers or the production of microalgae, but so far there is a low acceptability from consumers, mainly European consumers.

Recent studies indicate the exploitation and development of science in various research directions, such as analyzing the benefits-risks of the production of plant-based meat analogues, verifying the effectiveness of the methods used to detect *Salmonella,* finding innovative technologies. An alternative to environmental sustainability can be represented by plant-based meat analogues, contributing favorably to solving ethical, ideological and, not least, health-related problems.

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