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BIBLIOMETRIC MAPPING OF ARTIFICIAL MEAT THEMATIC USING VOSVIEWER

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ABSTRACT: This paper presents a bibliometric analysis and data-mapping technique that focuses on trends and thematic research on artificial meat. The VOSviewer software was used to visualize the literature on artificial meat from 2000 to 2023 using the ScienceDirect database. Various bibliometric techniques, including productivity and graphic mapping, have been used to determine the evolution of thematic areas using the most relevant journals and research topics. A cutting-edge research method, knowledge mapping, which is widely used in academia to identify key keywords and literature more scientifically and display them in schematic diagrams that are easy to understand, was used. The study retrieved and analyzed 72,420 original papers based on the following keywords: cultured meat and regulation (8,271 studies retrieved), plant-based protein and regulation (36,443 studies retrieved), insect-based protein (8,557 studies retrieved), and microbial protein (19,149 studies retrieved) to provide background information, popular themes, and knowledge structures. The analysis revealed a research gap and lack of collaboration between the authors. The mapping revealed that the dominant themes were cultured meat, plant proteins, and bioprocessing. It has also been discovered that there is disparity between the regulatory and nutritional aspects of artificial and conventional meat.
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Keywords: Artificial meat, plant protein, regulation, bibliometric-mapping

1. INTRODUCTION

Based on OECD and FAO projections, global animal flesh consumption is expected to increase by 2030 to \$ 31.24 billion compared to 2018-2020 (\$18–20 billion). This growth is driven by rising income and population, leading to greater availability of proteins in red meat, poultry, and seafood (OECD/FAO, 2021). Meat consumption is declining owing to changing preferences and aging populations. There is a demand for healthy meat containing bioactive compounds. Production requires substantial amounts of water, which causes emissions. While consumers enjoy meat but oppose animal harm, alternatives such as lab-grown meat exist (Cornelissen & Piqueras-Fiszman, 2022). Artificial meat is a byproduct of tissue engineering, animal biopsies, and enriched cells grown in cultivators and bioreactors (Kadim et al., 2015), which produce meat without killing animals (Goodwin and Shoulders, 2013). Artificial meat products include plant-based meat from plant materials, clean meat from animal cells, microbial- or insect-based meat, and synthetic meat derived from algae and fungi (Caporgno et al., 2020). This technology has multiple advantages, including the capacity to sustain a growing population, address concerns related to animal well-being, and reduce the environmental footprint (Goodwin and Shoulders, 2013; Chriki and Hocquette 2020; Chriki et al., 2022). Artificial meat became popular in 2002 (Goodwin & Shoulders, 2013; Kadim et al., 2015). In 1932, Winston Churchill's prediction-initiated exploration began in 2002. In 2007, a meat consortium was established to promote the production of muscle tissue for human consumption. Over the past few decades, various methods have been used to culture meat, bone, connective tissue, fat, and fibrous tissues (Kadim et al., 2015; Hubalek et al., 2022). However, the commercial production of artificial meat requires further research. Consumer opinions influence the industrial potential of artificial meat. This study examined trends, regulations, and research gaps. The bibliometric method analyzes themes through field structure visualization. Bibliometric analysis is increasingly being used across fields (Abdelwahab et al., 2023).

Using this approach, we identified key advances in the development of artificial meat products. These findings provide an eco-friendly alternative to traditional meats. We reviewed articles published between 2000 and 2023 to assess development and predict future directions. The key findings are as follows: Yap, Choudhury, and Suntornnond (2023) worked on the evolution of cultured meat, its progress, and drawbacks, and concluded that to ensure the success of the cultured meat industry, cultivated products must be both reproducible and safe for human consumption. Broucke et al. (2023) studied the nutritional regulations and safety of cultured meat and the requirements for regulation and legislation for safety. Ozhava et al. (2022) used cell sources to produce cultured products, and explored the use of alternative cell sources for the manufacture of cultured meat, such as birth tissues derived from living animals, which represents a potential option. Sugii et al. (2022) studied the sources and growth of cultured adipocytes and cultured meat and meat products with an emphasis on cultured fat and safety. Ye et al. (2022) worked on scaling artificial meat production and commercialization; enterprises must increase consumer awareness through marketing campaigns. Regulatory frameworks with agencies to ensure product safety standards. Reducing prices through economies of scale and supplier negotiations drives adoption. Production expansion ensures availability. Risk management through market research and contingency planning has enabled long-term success. Ching et al. (2022) focused on technical constraints, market acceptability, and the need to create food regulations for artificial meat to be legally marketed. Chen et al. (2022) discussed technological requirements for cultured meat production, emphasizing systematic innovation to transform cultured meat from lab to industrial-scale production. Lanzoni et al. (2022) focused on technical constraints, market acceptance, and food regulations required for artificial meat marketing. Levi et al. (2022) researched advances in tissue engineering with an emphasis on the safety of cell scaffolds and additives used to produce cultured meat. Fernandes et al. (2022) worked on scale-up and start-up ventures, and the need for innovation and investments to scale up the production of artificial meat. Seah et al. (2022) discussed innovative scaffolding technologies and potential scaffolding related to scale-up solutions for the production of cultured meat. Hubalek et al. (2022) analyzed cost-effective nutrient replacements for cell propagation and differentiation based on hydrolysates with a focus on opportunities for medium recyclability. Lee et al. (2022) studied the substances needed to produce cultured meat and the need for further research to grow food-grade cultured beef. Seah et al. (2022) reported that between 1997 and 2020, more than 190 products were patented for meat production. Ketelings, Kremers and de Boer (2021) reported on cultured meat safety, requiring risk assessment for human consumption. Jairath et al. (2021) investigated survivability of in vitro technology and design flaws in scaffold and bioreactor.

2. MATERIALS AND METHOD

2.1. Research Design

Bibliometric analysis has been widely used to create a framework for statistical inquiry that primarily focuses on libraries and information. This approach has been applied across academic disciplines (Mehmood, Zunaid & Madan, 2022). Qualitative research methods in literature reviews lack systematic organization and objectivity. New researchers have struggled with article identification because of their limited experience. Knowledge mapping provides an objective solution that reflects disciplinary history (Shen et al., 2023; Abdelwahab et al., 2023). Visualization was performed using VOS Viewer 1.6.19, enabling bibliographic coupling and co-occurrence analyses.

2.2. Data Mining and Strategy

ScienceDirect is a platform for peer-reviewed literature including open-access content in Elsevier journals and books. It served as the research object using analytical tools for evolutionary theme analysis. However, aggregating bibliometric data from multiple databases remains a challenge. Khuram et al. (2023) argued that a single research focus can examine thematic regions. The investigation was restricted to the literature published between 2000 and 2023.

2.3. Refinement of Mined Data

The search identified 72,420 articles, 1,362 of which were relevant after screening. After eliminating conference abstracts, letters, and misaligned articles, 379 remained. The title, author, abstract, and references are exported as plain text for the dataset. The data search methodology used five keyword combinations. The Research Information Systems (RIS) data file was stored for analysis.

2.4. Data Analysis

Co-occurrence and cluster analyses using keywords were used to examine the connections between the artificial meat themes. A co-occurrence network was created by analyzing the subject term frequency in studies representing literature interconnections. Visualization using VOS viewer highlighted hot topics and enabled the prediction of potential research subjects.

3.0. RESULTS OF LITERATURE SEARCH

ScienceDirect is a leading platform for peer-reviewed research with over 20 million pieces across 4,600 journals and 45,000 e-books. The software analyzed the keywords related to artificial meat, plant proteins, regulation, insects, and microbial proteins. This tool computes links, total link strengths, and keyword co-occurrence. Fig 1 shows the keywords artificial meat, plant protein, regulations, insect protein, and microbial protein, yielding 444 records, 22 clusters, 2147 links, and 2149 total link strengths. This increase in publications has led to a growing interest in artificial meat research. These results suggest the scope for further exploration of artificial meat production. The clusters encompassed themes related to emerging topics related to artificial meat. These findings offer insight into the key concepts of artificial meat. However, bibliometric studies of artificial meat are limited.

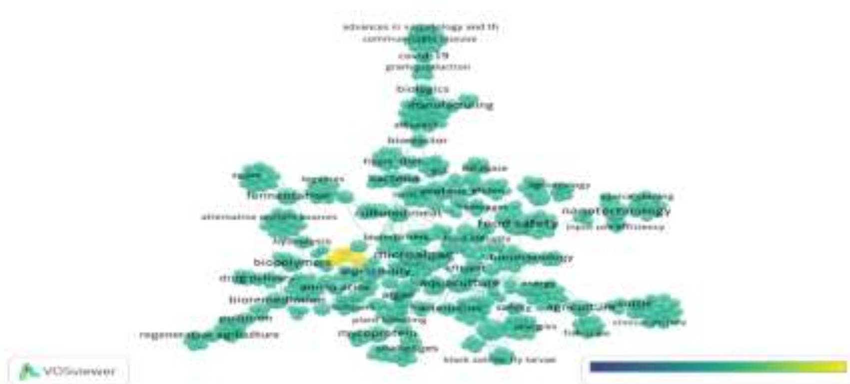

Fig 1: Raw textual data from ScienceDirect for VOSviewer software to generate network maps and tailored data showing co-occurrence networks of data based on the keyword Artificial.

3.1 Cultured meat

An analysis of the thematic results of the keyword 'cultured meat' was conducted, identifying 60 items, nine clusters, 197 links, and 221 total link strengths. To classify the clusters, distinguishable topics for each keyword and thematic distinctions based on frequently occurring words were examined (**Fig 2).**

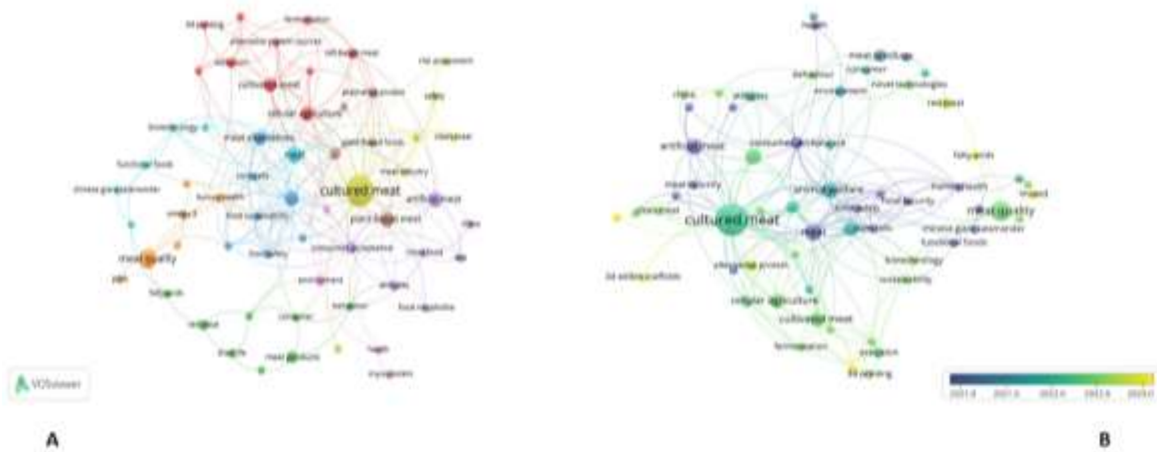

Fig 2: Co-occurrence of keywords through network visualization. As seen in (A), the keyword cultured meat formed nine clusters: Cluster 1 (10 items), Cluster 2 (8 items), Cluster 3 (7 items), Cluster 4 (7 items), Cluster 5 (7 items), Cluster 6 (7 items), Cluster 7 (6 items), Cluster 8 (5 items), and Cluster 9 (4 items) (B) colors ranging from blue (lowest score) to green to yellow (highest score) of keyword occurrence.

Cultured meat refers to meat produced in bioreactors using tissue engineering technology. To achieve this goal, several technologies have been developed. Levi et al. (2022) outlined four stages for producing artificial animal proteins: extraction of cells from a living animal, production of cell lines in a bioreactor, scaffolding, and maintenance of the cells.

3.1.1. Animal Cell Extraction

The extraction of animal cell lines involves tissue biopsies, pluripotent stem cells, and immortal cell lines. The use of immortal cell lines is unacceptable for artificial meat production due to ethical concerns. Primary cell lines are prone to degradation and require continuous isolation to maintain viability (Chen et al., 2022; Kim et al., 2023).

3.1.2. Cell Line Establishment

The feasibility of producing artificial meat depends on the isolation of cell lines from tissues. These cells multiply in a bioreactor with growth medium containing growth factors, hormones, amino acids, minerals, salts, vitamins, serum, antibiotics, glucose, and antifungal agents. Additives can enhance the sensory experience of artificial meat (Lanzoni et al., 2022). In addition to traditional culture media, edible byproducts have been suggested to improve the speed of cell growth.

3.1.3. Scaffolds and Scaffolding

Scaffolds are biodegradable, edible (Lanzoni et al., 2022), three-dimensional, rough, or porous. They possess both mechanical and chemical properties that promote cell maturation, which adds to the final sensory properties of meat (Seah et al., 2022; Zheng et al., 2022). Nutritionally rich plant proteins offer processing benefits and are safe to consume. Proteins from soy, wheat, zein, oats, peas, and cottonseed serve as scaffolds, although some require allergen labeling. Polysaccharide scaffolds aid cell growth, whereas chitosan is popular because of its compatibility and affordability (Handral et al., 2022; Yen et al., 2023). A recent approach is bio-fabrication that uses a mixture of cells and biological molecules to create cell-laden constructs (Lanzoni et al., 2022; Levi et al., 2022; Siddiqui et al., 2022). The objective is to develop substantial edifices and regulate the distribution of cell types even when multiple cell types are combined (Bomkamp et al., 2022; Lanzoni et al., 2022).

3.1.4. Cell Sustainability

3D scaffolds maintain cell viability using spinning flasks and perfusion bioreactors. Cells multiply and differentiate into bioreactors. Proteins and minerals in scaffolds activate cell development without attachment (Lanzoni et al., 2022; Yap et al., 2023). Tissue development requires the proliferation and differentiation of meat with a proper flavor and texture. Anchor sites are crucial for artificial meat production (Andreassen et al., 2022; Ozhava et al., 2022). Cell adhesion and suspension prevention can be achieved by blending biomaterials such as polystyrene, gelatin, collagen, and protein additives suitable for bioprinting (Handral et al., 2022). Cost constraints limit industrial production of cultured meat. In 2011, the Eat Just's chicken product was approved in Singapore. Three years after China's first artificial meat was produced in 2021, Aleph Farms printed a ribeye steak using 3D bioprinting (Levi et al., 2022).

3.2. Plant-Based Meat Alternatives

VOSviewer generates networks by showing the keyword clusters. Visualizing keywords reveals the relationship between plant-based meat alternatives and policies. Advances in meat substitutes are limited by their expensive manufacturing process. Plant proteins have been used as food sources. The plant-based meat technology surpasses other substitutes (Schot et al., 2023). Plant-based meat products with meat-like textures can be produced by extrusion, silking, and conditioning (Zhang et al., 2022). In the 1960s, extruded chunked products emerged as dry-texturized vegetable proteins. Twin-screw extruders create high-protein foods from plant proteins to produce meat-like products, vegetables, legumes, grains, and seeds (Siegrist & Hartmann, 2023).

3.2.1. Extrusion, Silking, and Conditioning of Plant-Based Meat

The two most commonly used extrusion techniques are high- and low-extrusion (Guyony et al., 2022; Zhang et al., 2022). The matrix was formulated by blending the proteins, fats, salts, and excipients. After mixing, the mixture was extruded with 60% moisture content and forced through a cooling die above 150°C.(Pietsch et al., 2019). Twin-screw extruders produce flesh-like products through their fibrous structures. These structures are improved by transglutaminase enzymes. To simulate the muscle tissue, protein powder and water were mixed to form a paste (Tehrani et al., 2017; Ubeyitogullari & Rizvi, 2020). Fig 3 Knowledge map visualization across 36,443 articles containing 47 items in eight clusters with 112 links. Larger clusters formed from keywords with thicker links exhibit stronger connections. The strongest bursts occurred in meat analogs from to 2021-2023.

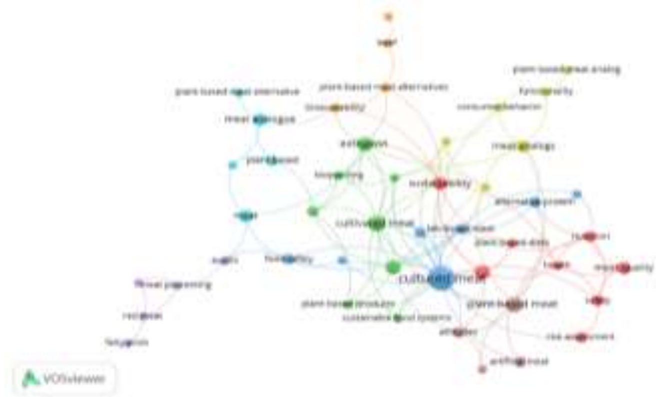

Fig 3: visualization of plant-based meat on regulations; cluster 1 (red), cluster 2 (green), cluster (dark green), cluster 3 (light green), cluster 4 (purple), cluster 5(light blue), cluster 6 (orange)

3.3. Microbial Protein

The number of published articles has increased over three years. Keyword analysis revealed high-pressure and ready-to-eat processing to be areas of strength. Previous studies have focused on novel techniques and innovative ingredients. The analysis in **Fig 5** indicates a research gap with seven (clusters), although future trends may combine AI with 3D printing. Microbial proteins are discussed in relation to their thematic occurrence.

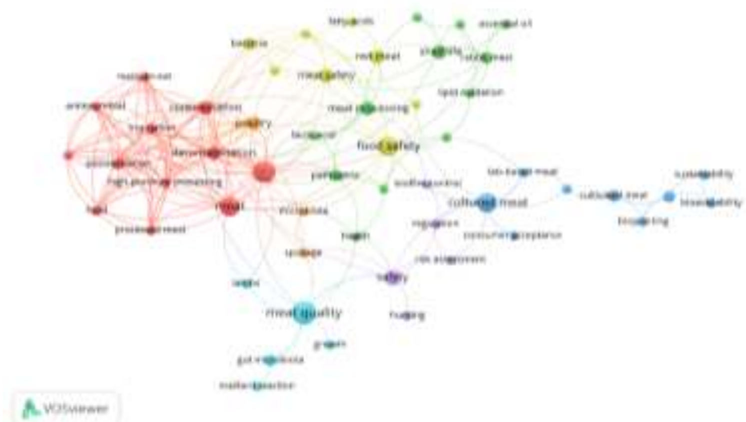

Fig 4: Thematic analysis of key microbial proteins. The colour range indicated different clusters

Microbial protein (M.P.) is the biomass of bacteria, yeast, filamentous fungi, and microalgae (Cardoso Alves et al., 2023; Van Peteghem et al., 2023). Environmental sustainability is crucial for the identification of new protein sources, particularly bacterial proteins. Researchers have studied autotrophic hydrogen-oxidizing bacteria that utilize nitrogen from agro-industrial wastes and human activities. These bacteria produce proteins while consuming minimal resources, resulting in low environmental impact on human food (Bedoya et al., 2022). Microalgae enable large-scale artificial meat production through high biomass yield and growth on non-arable land using saltwater. Plant-based meat products face textural challenges; however, potassium carbonate and alginate help achieve beef-like properties. Essential nutrients such as vitamins B-12, D, calcium, zinc, iron, and n-3 fatty acids can enhance nutritional value post-extrusion (Hadi and Brightwell, 2021). Fungi-derived foods include the fruiting bodies of edible mushrooms (Berger et al., 2022). Mycelium, the vegetative part of fungi, has been studied as a protein-rich meat alternative using various fungal species, such as molds and yeasts (Humpenöder et al., 2022; Gow and Lenardon, 2023). The protein content of the nutritional yeast biomass is notably high and has an ideal amino acid profile with minimal lipid content (Casas-Godoy et al., 2023). This biomass serves as artificial meat and stabilizer. Yeast biomass and extracts enhance flavor and act as vitamin carriers (Jach et al., 2022; Nanda et al., 2023).

3.3.1. Technology, Selection and Modification of Microprotein

3D printing creates products by layering materials without molds. The Digital Food Processing Initiative has developed personalized nutrition for military personnel based on their needs. Projects have focused on older adults with chewing difficulties to ensure adequate nutrition (Bedoya et al., 2022). Algal nutrients such as omega-3 fatty acids, beta-carotene, and astaxanthin benefit human health in a microbial protein diet. Genetic improvements may be required to enhance traits, such as yield, nutrition, and productivity. Microalgal genetics can be modified by DNA alteration or ultraviolet (UV) light using targeted mutagenesis (Torres-Tiji et al., 2020).

Algal nutrients such as omega-3 fatty acids and β-carotene benefit human health in protein-rich diets. Genetic improvements may enhance traits, such as yield and nutritional value. Microalgal genetics can be modified using DNA alterations or UV light for precise manipulation (Rashid et al., 2020). The key factors for selecting single-cell protein strains include nutrient requirements, fermentation performance, genetic stability, growth morphology, proteins, and purification complexity. Toxin production is of concern when bacteria are used as single-cell proteins (Alves et al., 2023).

3.4. Insect Protein

Entomophagy has gained popularity in recent years (Mancini & Antonioli, 2022). Viewer found 72 items, nine clusters, 289 links, and 324 link strengths from 9557 articles. These clusters were linked to the keywords for insects and alternative proteins. The purple path shows the connections between the clusters. Insect-based foods offer a high protein content while reducing greenhouse gases, water, and land use. Insect protein products are available on the German market (Van Huis, 2016). Tenebrio molitor, a mealworm species, is among the 12 most outstanding insects. It produces an edible mass comparable to that of livestock and contains high levels of proteins, minerals, and fats, making it a promising nutritional source (Dupont & Fiebelkorn, 2020; Geeraerts, De Vuyst and Leroy, 2020; Hawkey et al., 2021; Broucke et al., 2023).

Insect-based meat substitutes can replicate meat texture. The common edible insects include mealworms, crickets, and grasshoppers. Products, such as hamburgers, combine insects with plant flours and spices. T. Molitor proteins can replace pork in meat emulsions. Defatted flours from T. molitor and B. mori work in sausages, improving their acceptability.

A 40% pork and 10% mealworm blend created frankfurters with a good sensory quality. Protein isolates separate insect proteins through extraction. Artificial meat products bridge meat and meatless items with a similar acceptance. Insects in ready-food reduce food phobias. Although proteins require plant biomass for texture, insect biomass is a sustainable alternative. Plant-based insect products are more environmentally-friendly than meat products (Upcraft et al., 2021; Laroche et al., 2022; Smetana et al., 2023).

4.0. Customizing the nutrient profile in artificial meat

Artificial meat is a nonlethal meat substitute that is gaining popularity. Proteins, carbohydrates, lipids, neurons, and blood vessels create flavors, although scientists have not replicated all of these features. Production methods influence taste and fatty acids, allowing dietary customization (Balasubramanian et al., 2021). Scientists have cultivated and improved fat cell co-cultures to meet nutritional demands (Golkar-Narenji et al., 2022), providing artificial meat with a competitive advantage in terms of flourishing.

4.1. Nutritional Properties and Ethics

Cultured meat is crafted using animal cells cultivated in vitro, along with connective tissue, fat, and muscle cells. Skeletal muscles and adipocytes produce proteins, hormones, fatty acids, and cytokines (Broucke et al., 2023). Serum substitutes are crucial for the sustainability of synthetic meat. Mammalian cell culture, platelet lysate, horse serum or fetal bovine serum (FBS) can be used, but alternatives are needed due to scarcity.

An appropriate nutrient composition is essential for cell function. Improper-medium management leads to inadequate absorption and excess byproducts. The medium must be tailored to the cell type, as the requirements vary between phases (Hubalek et al., 2022; Ching et al., 2022). Understanding the nutritional characteristics of "artificial meat" versus traditional meat and guidelines for incorporating nutrients into lab-cultured meat. Conventional meat contains 18.1-24.2% protein, while artificial meat varies - microalgae contain 50-70% and insects 13-77% protein by dry weight (Fatima et al., 2023), The international Recommended Dietary Allowance for protein is 0.8 g/kg body weight, while UK Reference Nutrient Intake is 0.75 g/kg. These guidelines, which are based on nitrogen balance, have not been optimized for activity levels. Less active individuals require more protein to preserve their muscle, and essential amino acids are predominantly found in conventional meat (1.3-7.9%). Cultured meat may lack essential fatty acids and beneficial compounds such as conjugated linoleic acid from ruminant biohydrogenation, and l-amino acids are permitted only to enhance protein quality. Approval requires either a per-food basis or, in the US, specific conditions including 6.5 g of intact protein in daily adult intake (Lewis, 2012). Collagen is mainly composed of non-essential amino acids (3.3 – 14.3%); however, it also contains a moderate amount of lysine, which is a limiting amino acid in diets lacking meat (Fraeye et al. 2020). Fat (saturated fat (g) 0.2-10.8, Fat (g) 1.9-31.7, Energy (kcal) 106-146) Scientists attempt to replicate animal fats using plant oils. Although animal products provide diverse options, plant oils have uniform traits such as low melting points. Research has shown that substituting animal fats with plant oils to improve the structural quality of meat is challenging (Louis et al., 2023). Fatty acid requirements vary according to the cell line and the type used for cultivated meat production. Glucose was used at 5.5-55 mM concentrations, which typically matches human fasting blood glucose. Different cells have different glucose requirements. The Daily Value of total fat is 78 g/d (Li et al., 2022). An intramuscular fat content ranging from 3% to 7.3% is generally regarded as optimal for the flavor and acceptability of artificial meat products. Vitamin B12 (μg) (0.3.9-2.8) is crucial for cellular growth. It remains unclear whether the vitamin B12 levels in cultured meat match those in traditional meat. The absorption of vitamin B12 requires transcobalamin II protein for cell membrane translocation, presenting a challenge in achieving adequate B12 levels in cultured tissues (Hadi and Brightwell, 2021). The concentrations of vitamins B1, B6, B9, glutamine, and tryptophan were lower in CVE than in conventional medium. However, these nutrients can be supplemented by extraction and concentration techniques (Lee et al., 2022). Mineral concentrations in basal cell culture media, such as DMEM and RPMI1640, often lack zinc and selenium and require supplementation for cell growth. Ham's medium contained zinc sulfate heptahydrate, whereas IMDM contained sodium selenite. The body requires macro-minerals, including calcium, phosphorus, magnesium, sodium, potassium, chloride, and sulfur, but trace amounts of Fe, Mn, Cu, I, Zn, Co, fluoride, and Se.

Earthworm coelomic fluid, bovine ocular fluid, human platelet lysate, and sericin protein serve as alternatives to fetal bovine serum (FBS) and require environmental impact assessment. China's "Health China 2030" promotes food sustainability through reduced meat consumption, while the "Public Nutrition Plan" targets obesity by limiting fat (General Office of the State Council of China, 2016)(Ortega et al., 2022) and conforms to the Sustainable Development Goal (SDG) 2030.

4.2. Halal Nutrition and Interpretation of Artificial Meat

Foods are classified as halal or haram, based on Islamic teachings and scholarly agreements. Halal components must follow Sharia principles and be free from haram sources such as impurities, intoxicants, bribes, gambling, or poison. Halal meat comes from permitted land animals that are properly raised and slaughtered, while aquatic animals are halal except poisonous ones, such as amphibians, frogs, and crocodiles.

Artificial or cultured meat products must conform to Islamic teachings. These include animal cells, culture media, and scaffolds (Izhar et al., 2023). Non-poisonous, non-hazardous, and poisonous compounds are eliminated during processing. Halal meat is becoming a choice for most consumers regardless of their religious faith (Carrasco et al., 2022).

4.3. Culturing Towards Sustainable Nutrition

The adverse effects of industrial and agricultural activities have attracted increasing attention to food sustainability and sustainable food systems (Gustafson et al., 2022). Policymakers have emphasized the development of strategies and frameworks to support sustainability objectives, particularly in sustainable diet selection. Current nutrition models enable diet selection based on nutritional factors, but rarely address sustainability concerns (Aidoo et al., 2023). Artificial meat is a novel concept for generating clean meat with minimal environmental impacts. Land used for animal husbandry can be repurposed for carbon capture.

The food sector generates 26% of the global greenhouse gas emissions, with aquatic and livestock accounting for 31%. Emissions mainly originate from meat, dairy, eggs, and seafood, whereas methane from cattle, manure, and fishing vessels contribute to additional emissions (Ye et al., 2022). On-farm 'production' emissions account for 31% of total emissions, excluding land-use changes and supply chain emissions from animal feed crops. Land use contributes to 24% of food emissions, double that of livestock production, which accounts for 16% of the total emissions (Blignaut et al., 2022). In contrast to crops for human consumption, which comprise 8% of the total land use, agricultural expansion converts forests, grasslands, and carbon sinks into croplands or pastures, thereby releasing greenhouse gases (GHGs). "Land use" includes activities like bush burning and organic soil cultivation through plowing and soil overturning (Castonguay et al., 2023).

Recent progress in the reduction of food production emissions has been notable. Although renewable energy options exist, the decarbonization of agriculture remains unclear. Cultured meat offers a sustainable solution; however, preventing methane production in cattle remains impossible (Green et al., 2022). A sustainable nutritional model reduces environmental impacts while improving agricultural productivity. Promoting this requires upscaling the production through innovation.

4.4. Impact of Polyunsaturated Fatty Acid on the Nutritional Value of Artificial Meat

Animal fat is essential for the nutrition, flavor, and texture of meat. To create artificial meat with a full flavor and ensure nutrition and consistency, adipose tissue must be added (Yen et al., 2023). Peptides and aromatics from adipose tissue affect flavor. Muscle fat exists as intramuscular fat and as lipid droplets. During adipogenesis, stem cells become adipocytes and store triglycerides.

Phospholipid and triglyceride levels varied across muscle types. Mesenchymal cells, adipose-derived stem cells, or microsatellites form fat. Animal fat affects meat quality. Peroxisome proliferator-activated receptors control white adipocyte differentiation. Fatty acids act as transcription factors and energy sources (Zidarič et al., 2020). Adipose tissue ages into white adipose tissue, whereas muscle tissue requires three weeks to mature. Muscle fiber maturation is more complex than that of adipose tissue. Adipocytes form tissue structures like natural fat. Fat affects the flavor and texture of cultured meat PUFA levels, which can be controlled by altering its composition (Dohmen et al., 2022).

4.4.1. Metabolism Of Polyunsaturated Fatty Acids (PUFAs)

PUFAs constitute 7% of the total energy intake and 19-22% of the energy from fat in adults. Both sexes should be able to maintain these levels. PUFAs include omega-3 fatty acids, such as α-linolenic, stearidonic, eicosatetraenoic, eicosapentaenoic, and docosahexaenoic acids (Shahidi and Ambigaipalan, 2018; Mariamenatu and Abdu, 2021), and omega-6 fatty acids, which are essential fatty acids, such as linoleic, γ-linolenic, dihomo-γ-linolenic, arachidonic, adrenic, tetracosatetraenoic, and docosapentaenoic acids (Kris-Etherton et al., 2000; Chamorro et al., 2020). Long-chain polyunsaturated fatty acids (LCPUFAs) are produced through desaturation and elongation of fatty acid chains. These intermediates are essential for the functioning of the organism. Although vertebrates can synthesize EPA and DHA from alpha-linolenic acid (ALA), low conversion rates require dietary supplementation. Lichens and soil algae synthesize long-chain n-3 PUFAs, whereas photosynthetic tissues of plants contain only ALA and AL., The main sources of n-3 very-long-chain PUFAs in humans are vegetables, flax seeds, chia seeds, canola, walnuts, soybean oil, fish, krill oil, and algae. N-6 very-long-chain PUFA requirements are met by meat, eggs, and poultry. Foods enriched with n-3 fatty acids may help reduce illness and improve health (Agradi et al., 2023). PUFAs regulate fat deposition and muscle growth. Therefore, artificial meat requires n-3 and n-6 fatty acids.

Before intestinal absorption, polyunsaturated fatty acids must be hydrolyzed by pancreatic enzymes. Bile salts facilitate fatty acid absorption into mixed micelles. Under standard conditions, fat is efficiently absorbed (85-95%) from mixed micelles in the small intestine (Tan et al., 2023). Humans synthesize linoleic and linolenic acids, which are precursors of omega-6 and omega-3 fatty acids. Arachidonic, eicosapentaenoic, and docosahexaenoic acids are produced by elongases and desaturases (Lin et al., 2023). Young men convert approximately 8% of dietary alpha-linolenic acid (ALA) to eicosapentaenoic acid (EPA) and 0-4% to docosahexaenoic acid (DHA), whereas young women convert 21% to EPA and 9% to DHA. Young women are more efficient at generating long-chain polyunsaturated fatty acids (PUFA) from ALA. Given the essential roles of EPA and DHA in health and their limited dietary sources, they may be considered conditionally crucial nutrients. Blood fatty acid concentration is influenced by biological processes and nutrition. Humans produce linoleic and linolenic acids through desaturation and elongation, which compete with enzymes to produce arachidonic acid, EPA, and DHA. ALA can be enzymatically converted to EPA and DHA. A study of omnivores ($n = 8$) and vegetarians ($n = 12$) found that daily DHA supplementation (1.62 g) increased EPA, DPA, and DHA in serum and platelets, with reverse conversion rates of 7.4%-11.4% and 12.3-13.8%, suggesting that DHA supplementation is effective (Mariamenatu & Abdu, 2021).

4.4.2. Influence of Fatty Acid Modification on Animal Tissue

Meats consist of proteins, essential amino acids, and fat. Artificial meat can be created using microorganisms such as fish, rabbits, and krill, which contain polyunsaturated fatty acids (PUFAs). PUFAs must be added to artificial meat to provide health benefits (Agradi et al., 2023). Lipid peroxidation causes off-flavors that affect shelf life, and studies have examined tissue oxidation. Therefore, vitamin E can be used to prevent these issues. A diet with high omega-3 and low omega-6 levels modifies the food profiles. Rabbits fed flaxseed have high PUFA levels (Benatmane et al., 2011; Peiretti and Meineri, 2011; Rodríguez et al., 2019). Vitamin E should be added to animal feed to combat lipid oxidation, though research shows 30 mg/kg is insufficient to prevent deterioration.

5.0. REGULATIONS

5.1. Legislative and Regulatory Aspects

Regulatory frameworks differ across countries and continents (Post et al., 2020). Singapore approved the commercialization of cultivated chicken in 2020. Agencies such as the EFSA, FDA, and USDA have examined this issue. In the EU, cultured beef meets the EFSA's novel product guidelines (Hubalek et al., 2022). Under E.U. regulation 178/2002, artificial meat products must meet standards in Regulation 2015/2283 (Novel Food Regulation). Applications must be submitted to the EC. The EFSA assesses risks and guides authorization requests. The EC evaluates foods based on EFSA's examination and other factors including ethical aspects.(Ketelings et al., 2021; Broucke et al., 2023). A 2019 document outlined the USDA-FDA overview of cell-cultured food. The FDA oversees cell growth, while the USDA supervises manufacturing and labelling. Without safety guidelines, FBO licensing remains uncertain (Van Huis, 2016; Ding et al., 2021, Ketoue et al., 2021; Wood et al., 2023). The FDA regulates 3D printing for medical products, but not for food consumption. Key concerns with 3D-FP include risks of adulteration, allergens, contamination, health effects, and labelling issues. (Bedoya et al., 2022).

5.2. Startup Enterprises

The FDA has regulated 3D printing for medical products but not for food. Key concerns of 3D-FP include the risks of adulteration, allergens, contamination, long-term health effects, and labelling (Nobre, 2022). Eight cultured meat start-ups in Silicon Valley, an area known for entrepreneurship and influence, demonstrate how technological advances impact business development and predict industry futures (Fernandes et al., 2022). Companies such as Eat Just, Novel Farms, Bluu Seafood, SCiFi Foods, UPSIDE Foods, Jimi Biotech, and Joes Future Food have introduced artificial meat, such as cultured chicken, pig loins, lab-grown seafood, and burgers.

5.3. Patent

A patent for artificial meat was granted in 1999 to Willen van Eelen, Willem van Kooten and Wiete Westerhof (Fernandes et al., 2022). Understanding a firm's patent portfolio through public information is challenging due to filing delays. Impossible Foods excels in patent development, creating "mini-patent thickets." Their patent U.S. 9,700,067 yielded five patents and four pending applications, whereas their 2013 U.S. application 13/941,211 produced ten patents and seven applications. Impossible Foods invested heavily in patents, receiving grants for meat analogs, 3D food printing, and machine learning algorithms.

6.0. CONCLUSION AND PROSPECTS

A comprehensive examination of the artificial meat literature from 2000 to 2023 was conducted using VOS Viewer to uncover significant themes. These findings highlight the importance of evolution in the artificial meat industry. These results provide opportunities for the development of sustainable meat culture methods. Artificial meat minimizes the environmental impact of protein sources. However, several challenges remain. Development requires complex processes, with start-ups focusing on cell-based production. This study addresses these gaps in the literature and provides practical guidance. Further research could explore citation and co-citation analyses using VOS viewer for comprehensive bibliometric analysis.

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