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EMERGING TECHNOLOGIES FOR REFORMULATING MEAT PRODUCTS - A REVIEW

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Abstract

In the ever-evolving landscape of the food industry, the application of innovative technologies has become a crucial aspect of reformulating meat products to meet the changing demands and preferences of consumers and sustainability requirements. This review examines recent technological advancements in the production of innovative meat formulations, emphasizing improvements in safety, preservation, nutritional characteristics, and sensory properties while minimizing the use of synthetic additives. Furthermore, the review highlights challenges faced by the industry, including consumer acceptance, regulatory hurdles, and the need for cost-effective production methods. The potential of these innovative technologies to revolutionize the meat industry is also evaluated, with an emphasis on achieving a balance between health benefits, product quality, and sustainability.

***Key words**: innovative technologies, meat formulations, sustainability.*

INTRODUCTION

The reformulation of meat products has become a pressing concern in the food industry, driven by rising consumer awareness regarding health, sustainability, and animal welfare (Weiß et al., 2010).

As global populations expand and consumer dietary preferences evolve, the meat industry faces the challenge of developing products that not only satisfy traditional taste expectations but also align with contemporary nutritional requirements (Stephens et al., 2018).

The consumption of meat, particularly red meat, has been linked to various health issues, such as cardiovascular diseases and certain types of cancer (Bălănescu et al., 2024). Reformulation encompasses the modification of existing recipes, ingredients, and/or processing techniques, in order to enhance nutritional profiles (including salt and nitrates reduction), to improve food safety and security, and to reduce environmental footprints (Fanzo et al., 2023).

Meat products have been a staple of human diets for millennia, providing essential nutrients and flavors. Reformulation refers to the process of altering the composition of meat products to improve their nutritional profiles, enhance flavors, or cater to dietary restrictions. This trend is driven by several factors, including rising health consciousness among consumers, the growing demand for plant-based alternatives, and environmental concerns related to meat production (Parlasca et al., 2022). Historically, meat reformulation has taken various forms, from reducing fat content to introducing leaner cuts. In 1970, the emphasis was largely on reducing saturated fats due to the increasing awareness of their links to heart disease (Micha et al., 2017). The 1990s saw the introduction of products like turkey bacon and lean beef, which aimed to provide healthier options without sacrificing taste (Krause et al., 2018). More recently, the market has witnessed a surge in plant-based meat alternatives, driven by the need for sustainable food sources amidst rising global meat consumption (Safdar et al., 2022; Sethi et al., 2021). The use of plant derivatives helps stabilize meat compositions and improve technological capabilities, improving juiciness and increasing yields in finished products (Ianiţchi et al., 2023).

The reformulation of meat products addresses not only health considerations but also ethical concerns related to animal welfare and the environmental impact of meat production. As awareness of these issues grows, consumers are increasingly seeking transparency in food labelling and production practices. This has led to a rise in demand for products that are not only nutritious but also ethically sourced and produced in an environmentally sustainable manner (World Health Organization, 2021). The interplay of health, ethical, and environmental factors is reshaping the meat industry, prompting companies to innovate and adapt to meet the evolving expectations of consumers.

MATERIALS AND METHODS

A systematic literature review was conducted to identify emerging technologies for reformulating meat products. The search strategy involved querying multiple academic databases, including PubMed, Scopus, Web of Science, and Google Scholar. Keywords such as innovative technologies, meat formulations, sustainability, food processing technologies, and food innovation were used to retrieve relevant articles published between 2000 and 2024.

Studies were included in the review if they met the following criteria: Focused on innovative technologies applied in meat product reformulation; Discussed alternative protein sources, texturization methods, or novel processing techniques.

Data from the selected articles were extracted and categorized based on technology type, application, and outcomes. Key information included: Type of technology; Source of alternative ingredients; Impact on sensory properties, nutritional value, and consumer acceptance.

A narrative synthesis was employed to summarize findings from the selected studies. Technologies were grouped based on their functional applications in meat reformulation, and a comparative analysis was conducted to highlight advantages and limitations of each technology. Graphical representations, such as tables and figures, were created to illustrate key trends and insights.

While this review does not involve primary data collection, ethical considerations related to the use of animal products and alternative sources were addressed based on the findings from the reviewed literature. Discussions on sustainability and consumer perceptions of meat alternatives were included to provide a holistic view of reformulation technologies.

RESULTS AND DISCUSSIONS

TECHNOLOGICAL ADVANCES IN MEAT REFORMULATION

Innovative technologies play a critical role in reformulating meat products. They offer solutions to enhance nutritional value, extend shelf life, and improve sensory attributes without compromising the products quality. Technologies such as High-Pressure Processing (HPP), Modified Atmosphere Packaging (MAP), and Radio Frequency (RF) heating are paving the way for novel meat products that cater to health-conscious consumers while maintaining the sensory pleasure associated with traditional meat products (Rattan et al., 2014; Barbut, 2019).

High-Pressure Processing (HPP) is increasingly recognized as an innovative non-thermal food preservation technique that utilizes extremely high pressures, usually between 300 to 600 MPa, to effectively inactivate microorganisms and enzymes present in food products (Bolumar et al., 2020).

This method is particularly advantageous for meat products, as it extends shelf life while preserving the sensory and nutritional qualities of the food (Guillou et al., 2016; Pereira et al., 2010). By employing HPP, manufacturers can produce ready-to-eat and minimally processed meat products without the need for chemical preservatives, which is a significant benefit for health-consciou consumers (Balasubramaniam, 2021).

The HPP process works by applying uniform pressure to food products, which disrupts cellular structures and inactivates spoilage organisms and pathogens. This process occurs at room temperature, which helps to maintain the original flavor and texture of the meat, making it an attractive alternative to traditional thermal methods that can alter these properties (Devlieghere et al., 2004). Furthermore, HPP has been shown to effectively reduce the levels of harmful bacteria such as Listeria monocytogenes and Salmonella, enhancing food safety (Hayman et al., 2004).

One of the key advantages of HPP is its ability to retain the nutritional profile of meat products, including vitamins and minerals, which can be compromised by heat treatment (Gómez et al., 2020). Research has indicated that HPP-treated meats exhibit higher levels of certain nutrients compared to conventionally processed meats, making them a healthier choice for consumers seeking minimally processed options (Hayman et al., 2004).
Table 1 provides a comprehensive overview of the key parameters and considerations for HPP, reinforcing its role as an effective method for ensuring food safety while preserving product integrity.

Table 1. Parameters and considerations for High-Pressure Processing (HPP) technologies

Product types	Pressure	Processing time	Benefits	Reference
Ham	400-600 MPa	1-3 min	Reduction of pathogenic bacteria spoilage microorganisms.	Tao, et al. (2016)
Salami	300-600 MPa	3-5 min	Improved food safety and prevation of texture.	Hygreeva et al. (2016)
Sausages	400-600 MPa	3-5 min	Reduction of microbian flora, preservation of flavors and color.	Simonin et al. (2012)
Pâtés	300-500 MPa	3-5 min	Microbiological stabilization and preservation of creamy texture.	Goots, A. et al. (2020)
Game Meats	500-600 MPa	5-10 min	Increased safety and extended shelf life.	Simonin et al. (2012).
Bacon	300-500 MPa	2-4 min	Prevention of bacterial growth and preservation of flavor.	Huang et al. (2022)

Additionally, the application of HPP can result in a reduced reliance on preservatives, aligning with consumer trends favoring clean-label products. As a result, many food manufacturers are increasingly adopting HPP technology to meet growing consumer demands for natural and minimally processed foods (Siegrist & Hartmann, 2020). According to the information provided by Universal Pure (Figure 1), the HPP facility and its advantages are presented.
Process steps:
Packaging. Meat products are typically packaged in water and air-impermeable materials that can withstand high pressures. (Barbosa-Cánovas & Juliano, 2003).
Loading into the pressure chamber. The packaged product is placed into a pressure chamber.
Application of pressure. Pressure is applied uniformly throughout the chamber, usually using water. This pressure is maintained for several minutes (typically between 1-10 minutes, depending on the type of product and the specifics of the process) (Huang & Yang, 2016).

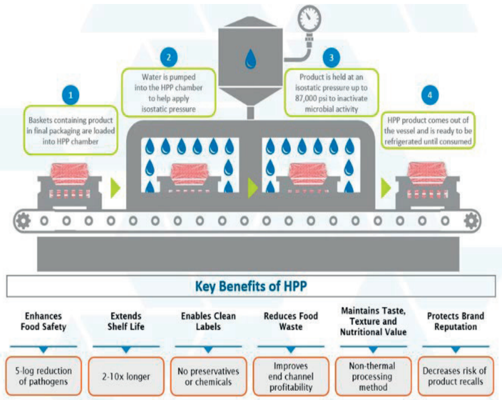

Figure 1. High-Pressure Processing benefits (https://universalpure.com/high-pressure-processing/)

Decompression. After the process is complete, the pressure is slowly reduced, and the product is removed from the chamber. (López-Caballero & Gómez-Guillén, 2018).
Modified Atmosphere Packaging (MAP). Is a widely recognized technique in the food packaging industry that enhances the shelf life and quality of perishable products. By altering the gas composition within the packaging-specifically by reducing the concentration of oxygen and increasing levels of carbon dioxide, MAP creates an environment that slows down spoilage processes, inhibits microbial growth, and minimizes oxidative reactions. This is particularly advantageous for fresh and processed meat products, where maintaining quality and freshness is critical (Kandeepan & Tahseen, 2022; Taormina, 2021).
The effectiveness of MAP can be attributed to its ability to create an environment that is less conducive to the growth of aerobic bacteria, which thrive in oxygen-rich atmospheres. By reducing oxygen levels, MAP not only slows

down the spoilage rate but also helps in preserving the sensory attributes of meat, such as color, flavor, and texture. Research has shown that MAP can extend the shelf life of various meat products, including beef, pork, and poultry, while also maintaining their nutritional value (Skandamis & Nychas, 2002; Aksu et al., 2005). MAP is a complementary technology that modifies the gas composition inside packaging to slow microbial growth and oxidative reactions according some researchers (Table 2). This is achieved by reducing oxygen levels (0-1%), increasing carbon dioxide (20-80%), and using nitrogen as a filler gas to maintain package integrity. Packaging materials with barrier properties are essential to minimize gas exchange and preserve the modified atmosphere.

Table 2. Parameters and considerations for Modified Atmosphere Packaging (MAP)

Product types	CO_2	N_2	Benefits	Reference
Ham	20%	80%	Extended shelf life, preservation color and flavor.	Gennadios, A. (2001)
Salami	40%	60%	Control of bacterial growth, preservation texture.	Nobile et al. (2023)
Sausages	20%	80%	Prevention rancidity, preservation color and flavor.	Koutsoumanis, K.,& Nychas, G.J.E. (2000)
Pâtés	30%	70%	Extended shelf life, maintenance creamy texture.	Ahn, D.U. & Lee, K. (2008)
Game Meats	40%	60%	Extended shelf life, control pathogenic bacteria.	Gunter, J. (2002)
Bacon	25%	75%	Reduced oxidation, preservation freshness.	Li, X., et al. (2018)

Moreover, the implementation of MAP can lead to reduced food waste, making it an environmentally friendly option as well. The technique has gained popularity in both retail and food service sectors, contributing to the global effort to enhance food preservation and reduce spoilage (Majid et al., 2018; Dalla Rosa, M., 2019).

Summarising, MAP is a crucial technology in the food industry, particularly for meat products, offering extended shelf life and improved quality through the strategic manipulation of gas compositions within the packaging environment.

As shown in Figure 2, MAP utilizes a specific gas composition to enhance the preservation of food products according to Blonder (2024).

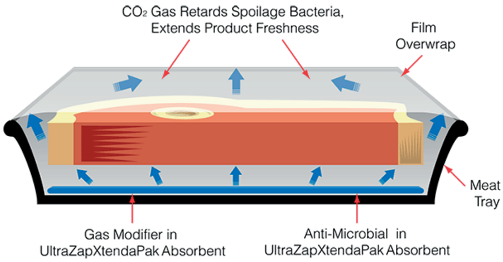

Figure 2. Modified Atmosphere Packaging principle (https://genuineideas.com/ArticlesIndex/sramap.html)

Stages of the process MAP:

Product preparation. The meat is cleaned.

Packaging: Products are placed in airtight containers to preserve freshness (Kandeepan & Tahseen, 2022).

Gas injection. Gases are injected to replace air, enhancing preservation (Kandeepan & Tahseen, 2022). This can be done through various methods, such as pumping gas into a controlled environment or using pre-mixed gases.

Sealing. The packaging must be sealed to maintain the modified atmosphere (McMillin, KW, 2020).

Radio frequency (RF) heating is gaining recognition as a transformative technology in the meat processing industry. This method utilizes electromagnetic waves to generate heat uniformly throughout meat products, leading to consistent cooking results and enhanced texture (Piyasena et al., 2007; Jojo & Mahendran, 2013). One of the standout advantages of RF heating is its ability to rapidly thaw frozen meats. Traditional thawing methods can be time-consuming and may compromise product quality, but RF technology significantly reduces processing times while minimizing energy consumption (Jiao et al., 2018; Di Rosa et al., 2019).

The efficiency of RF heating contributes not only to operational productivity but also to improved sensory characteristics of meat. Studies have demonstrated that RF-treated meats exhibit enhanced flavor profiles and increased tenderness, attributes that are crucial for consumer satisfaction (Hassoun et al., 2020;

Elzalaky, E., 2024). Moreover, the uniform heating capability of RF technology helps in minimizing the risk of uneven cooking, which can lead to food safety concerns (Rebezov et al., 2022). The working parameters for radio frequency heating are presented in Table 3 (Kauffman & Hsu, 2018).

Table 3. Parameters and considerations for Radio Frequency (RF) Heating

Frequency range	13.56 MHz to 27.12 MHz
Heating time	from seconds to minutes
Temperature control	65-75°C
Application types	for both cooking and thawing of meat products
Energy efficiency	reduce processing times and energy consumption
Quality maintenance	helps in preserving texture and moisture content by preventing overcooking
Reference	Kauffman, J. F., & Hsu, Y. (2018)

In addition to its advantages in thawing and cooking, RF technology is also being explored for its potential in marinating processes, where it can facilitate deeper penetration of marinades into meat tissues, further enhancing flavor and tenderness (Rahman et al., 2023). The integration of RF heating into meat processing systems presents a promising avenue for improving product quality and operational efficiency. In Figure 3, the difference between microwave heating and radiofrequency heating is illustrated according to Xiong (2022).

RF wave generation. RF installations utilize a wave generator that produces electromagnetic radiation at specific frequencies, typically between 13.56 MHz and 27.12 MHz. These frequencies are chosen for their ability to be efficiently absorbed by the water, fats, and proteins present in meat (Marra & Lyng, 2009).

Interaction with matter. When RF waves are applied to meat products, they induce movement in the water molecules, generating heat through internal friction (Raikos & Ranawana, 2019). This process results in heat propagation that occurs uniformly throughout the mass of the product, contrasting with traditional cooking methods that often lead to significant variability in internal temperature (Jiao et al., 2018).

Process control. RF installations come equipped with advanced control systems to monitor critical parameters such as temperature and exposure time. This capability ensures consistent and microbiologically safe results (Altemimi et al., 2019).

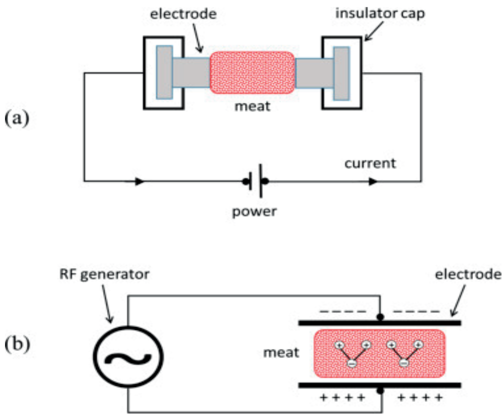

Figure 3. The difference between microwave heating and radio frequency heating (https://www.sciencedirect.com/science/article/abs/pii/B9780323854085000194)

The integration of novel processing techniques such as HPP, MAP, and RF heating into the meat industry represents a significant advancement in food preservation technologies. As consumer preferences continue to shift towards natural and preservative-free products, these innovative techniques will play a crucial role in meeting market demands and enhancing food sustainability.

CHALLENGES IN THE MEAT INDUSTRY

Despite significant advancements in reformulation technologies, the meat industry continues to face several challenges that can hinder the widespread adoption and success of healthier, reformulated meat products. These challenges span regulatory hurdles, consumer skepticism, and supply chain constraints, all of which need to be carefully managed for the continued growth of the industry.

Regulatory hurdles

One of the primary challenges in the meat industry is navigating the complex web of regulations that govern food safety and labeling. Reformulated meat products often require new labeling to communicate changes in ingredients, nutritional content, and potential allergens. The U.S. Department of Agriculture (USDA) and the Food and Drug Administration (FDA) have established stringent guidelines that can delay the market entry of new products (Harrison & Weller, 2020). Regulatory frameworks vary significantly across countries, complicating international trade and market expansion (Katz et al., 2018).

Consumer skepticism

Consumer skepticism presents another formidable challenge. Many consumers are hesitant to adopt reformulated meat products due to a lack of trust in food technology and a preference for traditional meat products (Silva, 2024). Misinformation regarding health benefits and the perception of artificial ingredients can deter consumers from trying these products (Bryant & Barnett, 2019). Effective communication strategies and transparent marketing are essential to overcome these barriers.

Supply chain constraints

The supply chain for meat products is complex and often inflexible. Reformulating meat products requires sourcing new ingredients and establishing relationships with suppliers who can provide the necessary raw materials. Additionally, processing facilities may need upgrades to accommodate new formulations, which can be cost-prohibitive (Caccialanza et al., 2023). Disruptions in the supply chain, as seen during the COVID-19 pandemic, further complicate the introduction of new products (Jiménez-Colmenero, 2000).

Consumer education and awareness

Educating consumers about the benefits of reformulated meat products is crucial for market acceptance. Many consumers lack knowledge about the nutritional advantages of these products, which can lead to misconceptions (Siegrist & Hartmann, 2020). Public awareness campaigns that highlight the health benefits and sustainability aspects of reformulated meat can help shift consumer perceptions (Teixeira & Rodrigues, 2021).

Competition from plant-based alternatives

The rise of plant-based alternatives poses a significant challenge to the meat industry. Companies producing meat alternatives are investing heavily in marketing and product development, which can draw consumers away from traditional meat products (Andreani et al., 2023). To remain competitive, the meat industry must innovate and demonstrate the advantages of reformulated meat products over plant-based options (Banach et al., 2022).

Economic factors

Economic factors, including the cost of reformulation and consumer willingness to pay for healthier options, also play a crucial role in the adoption of reformulated meat products (Font-i-Furnols & Guerrero, 2014). While some consumers are willing to pay a premium for healthier products, others may prioritize price over health benefits (Godfray et al., 2018). The industry must find ways to balance cost and quality to remain appealing to a broad consumer base.

Sustainability concerns

Sustainability is increasingly important to consumers, with many seeking products that have a lower environmental impact (Poore & Nemecek, 2018). Reformulated meat products can be positioned as more sustainable options, but the industry must ensure that the entire production process aligns with sustainability goals (Kumar et al., 2022). This includes addressing issues related to resource use, emissions, and waste management.

Health trends

Evolving health trends can also influence consumer preferences. The increasing prevalence of diet-related health issues, such as obesity and cardiovascular diseases, has led consumers to seek healthier food options (World Health Organization, 2021). The meat industry must respond to these trends by reformulating products to meet consumer health needs while maintaining taste and quality.

Ethical considerations

Ethical concerns regarding animal welfare and production practices also impact consumer choices. Many consumers are becoming more conscious of the ethical implications of their food choices, leading to a demand for more humane production methods (Sanchez-Sabate & Sabaté, 2019). The meat industry must address these concerns through transparency and improved practices to retain consumer trust.

SENSORY PROPERTIES AND CONSUMER ACCEPTANCE FOR MEAT PRODUCTS REFORMULATED

Reformulated meat products have become an increasingly popular choice among consumers, driven by health, environmental, and sustainability concerns. These products, which include meat with reduced fat content, additives, or alternative ingredients, must meet certain sensory properties to gain consumer acceptance. In this context, we will explore the main sensory characteristics of reformulated meat and how they influence consumer acceptance.

Sensory properties of reformulated meat products

Appearance. The visual aspect of meat products is essential. Reformulated meat must possess an attractive color and a consistent appearance that does not significantly differ from traditional products. Studies indicate that consumers appreciate meat that looks fresh and natural (Bou-Mitri et al., 2021).

Texture. Texture plays a crucial role in consumer acceptance. Reformulated meat products need to have a pleasant texture that mimics traditional meat. Research has shown that modifications in the reformulation process can affect texture, and consumers prefer a texture similar to that of unprocessed meat (Silva et al., 2019).

Aroma. Aroma is another determining factor. Reformulated products must have a pleasant aroma that does not reveal the alternative ingredients used. Natural additives, such as spices and herbs, can enhance aroma and acceptance (Sohail et al., 2022).

Taste. Undoubtedly, taste is the most critical aspect of consumer acceptance. Reformulated meat products must provide a satisfying taste experience. Studies have shown that taste significantly influences consumer preferences, and reformulations that maintain a flavor similar to that of traditional meat enjoy higher acceptance (Hong et al., 2023).

Sensory vs. nutritional. Often, there is a tension between sensory properties and nutritional benefits. For example, a reformulation that reduces fat may negatively impact texture and taste. Consumers are often willing to make trade-offs, but it is essential for reformulated products to strike a balance between these aspects (Botez et al., 2017).

Consumer acceptance of reformulated meat products depends on several factors:

Health awareness. Consumers are increasingly aware of the impact of diet on health. They are more likely to accept reformulated products that offer nutritional benefits, such as lower fat content or higher protein levels (Jaenke et al., 2017).

Perception of naturalness. Products perceived as more natural or containing simple, recognizable ingredients enjoy higher acceptance. Clear and transparent labeling of ingredients can influence purchase decisions (Jürkenbeck, 2023).

Price. Price remains an important factor in purchasing decisions. Reformulated products perceived to have good value for money are more attractive to consumers (Grasso et al., 2014).

Past experiences. Acceptance can be influenced by consumers' past experiences with similar products. If a consumer has had a positive experience with a reformulated meat product, they are more likely to try other products in the same category (Garmyn, A., 2020).

Dietary trends. Changes in dietary trends, such as the growing interest in plant-based diets, can influence the acceptance of reformulated meat products. Products that align with these trends are more likely to be accepted by consumers (Onyeaka et al., 2023).

CONCLUSIONS

The reformulation of meat products using emerging technologies represents a promising avenue for addressing health, safety, and sustainability challenges in the meat industry. Innovations such as HPP, MAP, and RF heating have demonstrated significant potential in enhancing the quality and safety of reformulated meats. However, successful implementation requires an integrated approach that considers sensory properties, consumer acceptance, and economic feasibility. As the industry continues to evolve, collaboration between researchers, manufacturers, and policymakers will be essential to overcome existing challenges and unlock the full potential of meat reformulation.

REFERENCES

Ahn, D. U., & Lee, K. (2008). Modified atmosphere packaging of meat products. *Advances in meat processing technology*, 225–236.

Aksu, M. İ., Kaya, M., & Ockerman, H. W. (2005). Effect of modified atmosphere packaging and temperature on the shelf life of sliced pastirma produced from frozen/thawed meat. *Journal of Food Processing and Preservation, 29*(5-6), 302–320. https://doi.org/10.1111/j.1745-4573.2005.08404.x

Altemimi, A., Aziz, S. N., Al-Hilphy, A. R. S., Lakhssassi, N., Watson, D. G., & Ibrahim, S. A. (2019). Critical review of radio-frequency (RF) heating applications in food processing. *Food Quality and Safety, 3*(2), 81–91. https://doi.org/10.1093/fqsafe/fyz002

Andreani, G., Sogari, G., Marti, A., Froldi, F., Dagevos, H., & Martini, D. (2023). Plant-based meat alternatives: Technological, nutritional, environmental, market, and social challenges and opportunities. *Nutrients, 15*(2), 452. https://doi.org/10.3390/nu15020452

Banach, J. L., van der Berg, J. P., Kleter, G., van Bokhorst-van de Veen, H., Bastiaan-Net, S., Pouvreau, L., & van Asselt, E. D. (2022). Alternative proteins for meat and dairy replacers: Food safety and future trends. *Critical Reviews in Food Science and Nutrition*, *63*(32), 11063–11080. https://doi.org/10.1080/10408398.2022.2089625

Balasubramaniam, V. M. (2021). Process development of high pressure-based technologies for food: Research advances and future perspectives. *Current Opinion in Food Science, 42*, 248–256. https://doi.org/10.1016/j.cofs.2021.10.001

Bălănescu, M. (2024). The effects of meat consumption on the health of consumer. *Animal Science Journal, 1*(1), 1–10. Retrieved from https://animalsciencejournal.usamv.ro/pdf/2024/issue_1/Art59.pdf

Barbosa-Cánovas, G. V., & Juliano, P. (2003). High pressure processing of food: Principles, technology, and applications. *Food Engineering Reviews, 1*(3), 189–203.

Barbut, S. (2019). *The science of poultry and meat processing*. Guelph, USA: University of Guelph Press.

Blonder, G. (2024). Modified Atmosphere Packaging principle. *GenuineIdeas*. Retrieved from https://genuineideas.com/ArticlesIndex/sramap.html

Bolumar, T., Orlien, V., Sikes, A., Aganovic, K., Bak, K. H., Guyon, C., Stübler, A. S., de Lamballerie, M., Hertel, C., & Brüggemann, D. A. (2020). High-pressure processing of meat: Molecular impacts and industrial applications. *Comprehensive Reviews in Food Science and Food Safety, 20*(1), 332–368. https://doi.org/10.1111/1541-4337.12670

Botez, E., Nistor, O. V., Andronoiu, D. G., Mocanu, G. D., & Ghinea, I. O. (2017). Meat product reformulation: Nutritional benefits and effects on human health. In *Functional food-Improve health through adequate food*. IntechOpen, DOI: 10.5772/intechopen.69118.

Bou-Mitri, C., Abdessater, M., Zgheib, H., & Akiki, Z. (2021). Food packaging design and consumer perception of the product quality, safety, healthiness and preference. *Nutrition and Food Science, 51*(1), 71–86. https://doi.org/10.1108/NFS-02-2020-0039

Bryant, C. J., & Barnett, J. C. (2019). Consumer acceptance of cultured meat: A systematic review. *Meat Science, 143*, 101–108. https://doi.org/10.1016/j.meatsci.2018.05.008

Caccialanza, A., Cerrato, D., & Galli, D. (2023). Sustainability practices and challenges in the meat supply chain: A systematic literature review. *British Food Journal, 125*(12), 4470–4497.

Dalla Rosa, M. (2019). Packaging sustainability in the meat industry. In C. M. Galanakis (Ed.), *Sustainable food systems from agriculture to industry: Improving production and processing*, 229–254. New York, USA: Academic Press. https://doi.org/10.1016/B978-0-12-814874-7.00009-2

Devlieghere, F., Vermeiren, L., & Debevere, J. (2004). New preservation technologies: Possibilities and limitations. *International Dairy Journal, 14*(4), 273–285. https://doi.org/10.1016/j.idairyj.2003.07.002

Di Rosa, A. R., Bressan, F., Leone, F., Chiofalo, B., & Lo Presti, V. (2019). Radio frequency heating on food of animal origin: A review. *European Food Research and Technology, 245*(9), 1787–1797. https://doi.org/10.1007/s00217-019-03319-8

Elzalaky, E. (2024). Methods for enhancing meat tenderness a main key factor of meat palatability: A review. *Alexandria Journal of Food Science and Technology, 22*(1), 25–36.

Fanzo, J., McLaren, R., Bellows, A., & Carducci, B. (2023). Challenges and opportunities for increasing the effectiveness of food reformulation and fortification to improve dietary and nutrition outcomes. *Food Policy, 118*, Article 102515. https://doi.org/10.1016/j.foodpol.2023.102515

Font-i-Furnols, M., & Guerrero, L. (2014). Consumer preference, behavior and perception about meat and meat products: An overview. *Meat Science, 98*(3), 361371. ttps://doi.org/10.1016/j.meatsci.2014.06.025

Garmyn, A. (2020). Consumer preferences and acceptance of meat products. *Foods, 9*(6), 708. https://doi.org/10.3390/foods9060708

Gennadios, A. (2001). Modified atmosphere packaging of meat and meat products. *Meat Science, 57*(2), 145–152.

Godfray, H. C. J., Aveyard, P., Garnett, T., Hall, J. W., Key, T. J., Lorimer, J., Pierrehumbert, R. T., Scarborough, P., Springmann, M., & Jebb, S. A. (2018). Meat consumption, health, and the environment. *Science, 361* (6400), 5324. https://doi.org/10.1126/science.aam5324

Gómez, I., Janardhanan, R., Ibañez, F. C., & Beriain, M. J. (2020). The effects of processing and preservation technologies on meat quality: Sensory and nutritional aspects. *Foods*, *9*(10), 1416. https://doi.org/10.3390/foods9101416

Goots, V., Koval, O., & Bondar, S. (2020). Simulation of high pressure meat pate processing. *Proceedings of University of Ruse, 59* (10.2), 60–67. https://dspace.nuft.edu.ua/handle/123456789/34127

Grasso, S., Brunton, N. P., Lyng, J. G., Lalor, F., & Monahan, F. J. (2014). Healthy processed meat products – Regulatory, reformulation and consumer challenges. *Trends in Food Science & Technology, 39*(1), 4–17. https://doi.org/10.1016/j.tifs.2014.06.006

Guillou, S., Lerasle, M., Simonin, H., & Federighi, M. (2016). *High-pressure processing of meat and meat products*. In E. J. Cummins & J. G. Lyng. Hoboken, USA: Wiley Publishing House. https://doi.org/10.1002/9781118350676.ch3

Gunter, J. (2002). The effect of modified atmosphere packaging on wild game meat. *Wildlife Biology, 8*(3), 213–218.

Harrison, R., & Weller, M. (2020). Regulatory frameworks for reformulated meat: Challenges and implications. *FoodPolicy, 96*, 101824. https://doi.org/10.1016/j.foodpol.2020.101824

Hassoun, A., Ojha, S., Tiwari, B., Rustad, T., Nilsen, H., Heia, K., Cozzolino, D., Bekhit, A. E.-D., Biancolillo, A., & Wold, J. P. (2020). Monitoring thermal and non-thermal treatments during processing of muscle foods: A comprehensive review of recent technological advances. *Applied Sciences, 10*(19), Article 6802. https://doi.org/10.3390/app10196802

Hayman, M. M., Baxter, I., O'Riordan, P. J., & Stewart, C. M. (2004). Effects of high-pressure processing on the safety, quality, and shelf life of ready-to-eat meats. *Journal of Food Protection, 67*(8), 1709–1718. https://doi.org/10.4315/0362-028X-67.8.1709

Hong, X., Li, C., Wang, L., Wang, M., Grasso, S., & Monahan, F. J. (2023). Consumer preferences for processed meat reformulation strategies: A prototype for sensory evaluation combined with a choice-based conjoint experiment. *Agriculture, 13*(2), 234. https://doi.org/10.3390/agriculture13020234

Huang, C., & Yang, X. (2016). The impact of high pressure processing on meat products: A review. *Journal of Food Science, 81*(11), R2694–R2704.

Huang, Y., & Xiong, S. (2022). Effect of high-pressure combined with coating on quality of sodium-reduced sliced smoke-cured bacon. *Journal of Food Processing and Preservation, 46*(10), 16961. https://doi.org/10.1111/jfpp.16961

Hygreeva, D., & Pandey, M. C. (2016). Novel approaches in improving the quality and safety aspects of processed meat products through high pressure processing technology - A review. *Trends in Food Science & Technology, 54*, 175–185. https://doi.org/10.1016/j.tifs.2016.06.002

Ianițchi, D., Pătrașcu, L., Cercel, F., Dragomir, N., Vlad, I., & Maftei, M. (2023). The effect of protein derivatives and starch addition on some quality characteristics of beef emulsions and gels. *Agriculture, 13*(4), 772. https://www.mdpi.com/2077-0472/13/4/772

Jaenke, R., Barzi, F., McMahon, E., Webster, J., & Brimblecombe, J. (2017). Consumer acceptance of reformulated food products: A systematic review and meta-analysis of salt-reduced foods. *Critical Reviews in Food Science and Nutrition, 57*(16), 3357–3372. https://doi.org/10.1080/10408398.2015.1118009

Jiao, Y., Tang, J., Wang, Y., & Koral, T. L. (2018). Radio-frequency applications for food processing and safety. *Annual Review of Food Science and Technology, 9*, 105–127. https://doi.org/10.1146/annurev-food-041715-033038

Jiménez-Colmenero, F. (2000). Relevant factors in strategies for fat reduction in meat products. *Trends in Food Science & Technology, 11*(2), 56–66. https://doi.org/10.1016/S0924-2244(00)00042-X

Jojo, S., & Mahendran, R. (2013). Radio frequency heating and its application in food processing: A review. *Journal of Food Processing and Technology, 4*(9), 1–11.

Jürkenbeck, K. (2023). Consumer trust in organic food producers and its influence on consumers' attitudes toward food reformulation and its sensory consequences. *Food and Humanity, 1*, 793–799. https://doi.org/10.1016/j.foohum.2023.07.031

Kandeepan, G., & Tahseen, A. (2022). Modified atmosphere packaging (MAP) of meat and meat products: A review. *Journal of Packaging Technology and Research, 6*(2), 137–148. https://doi.org/10.1007/s41783-022-00139-2

Katz, B., & Matz, M. (2018). Global perspectives on meat regulation: A comparative analysis. *Journal of Food Law & Policy, 14*(1), 1–22.

Kauffman, J. F., & Hsu, Y. (2018). Radio frequency heating for food processing: A review. *Critical Reviews in Food Science and Nutrition, 58*(14), 2335–2348.

Koutsoumanis, K., & Nychas, G. J. E. (2000). Effect of modified atmosphere packaging on the shelf life of fresh sausages. *Meat Science, 54*(3), 327–333. https://doi.org/10.1016/S0309-1740(00)00138-7

Krause, M., Kauffmann, A., & Meyer, J. (2018). Reformulation of meat products: A review. *Meat Science,145*, 101109. https://doi.org/10.1016/j.meatsci.2018.06.010

Kumar, P., Abubakar, A. A., Verma, A. K., Umaraw, P., Ahmed, M. A., Mehta, N., et al. (2022). New insights in improving sustainability in meat production: Opportunities and challenges. *Critical Reviews in Food Science and Nutrition, 62*(35), 11830–11858. https://doi.org/10.1080/10408398.2022.2096562

Li, X., Li, C., Ye, H., Wang, Z., Wu, X., Han, Y., & Xu, B. (2018). Changes in the microbial communities in vacuum-packaged smoked bacon during storage. *Food Microbiology, 76*, 156–165. https://doi.org/10.1016/j.fm.2018.08.007

López-Caballero, M. E., & Gómez-Guillén, M. C. (2018). High pressure processing of meat and meat products: Quality and safety aspects. *Meat Science, 145*, 210–218.

Majid, I., Nayik, G. A., Dar, S. M., & Nanda, V. (2018). Novel food packaging technologies: Innovations and future prospective. *Journal of the Saudi Society of AgriculturalSciences, 17*(4), 454462. https://doi.org/10.1016/j.jssas.2016.11.003

Marra, F., Zhang, L., & Lyng, J. G. (2009). Radio frequency treatment of foods: Review of recent advances. *Journal of Food Engineering, 91*(4), 497–508. https://doi.org/10.1016/j.jfoodeng.2008.10.015

McMillin, K. W. (2020). Packaging in Modified Atmospheres. *Food Safety Engineering*, 693–718.

Micha, R., Peñalvo, J. L., Cudhea, F., Imamura, F., Rehm, C. D., & Mozaffarian, D. (2017). Association between dietary factors and mortality from heart disease, stroke, and type diabetes in the United States. *JAMA Internal Medicine, 177*(10), 1497–1506. https://doi.org/10.1001/jama.2017.0947

Nobile, M., Chiesa, L. M., Arioli, F., & Panseri, S. (2023). Bio-based packaging combined to protective atmosphere to manage shelf life of salami to enhance food safety and product quality. *Meat Science, 203*, 109366. https://doi.org/10.1016/j.meatsci.2023.109366

Onyeaka, H., Nwaiwu, O., Obileke, K., Miri, T., & Al-Sharify, Z. T. (2023). Global nutritional challenges of reformulated food: A review. *Food Science & Nutrition, 11*(5), 1923–1939. https://doi.org/10.1002/fsn3.3286

Parlasca, M. C., & Qaim, M. (2022). Meat consumption and sustainability. *Annual Review of Resource Economics, 14*, 17–41. https://doi.org/10.1146/annurev-resource-111820-032340

Pereira, R. N., & Vicente, A. A. (2010). Environmental impact of novel thermal and non-thermal technologies in food processing. *Food Research International, 43*(7), 1766–1779. https://doi.org/10.1016/j.foodres.2009.09.013

Piyasena, P., Dussault, C., Koutchma, T., Ramaswamy, H. S., & Awuah, G. B. (2007). Radio frequency heating of foods: Principles, applications and related properties—A review. *Critical Reviews in Food Science and Nutrition, 43*(6), 587–606. https://doi.org/10.1080/10408690390251129

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science, 361*(6400), 987–992. https://doi.org/10.1126/science.aaq0216

Raikos, V., & Ranawana, V. (Eds.). (2019). *Reformulation as a strategy for developing healthier food products*. Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-030-23621-2

Rahman, S. M. E., Islam, S., Pan, J., Kong, D., Xi, Q., Du, Q., Yang, Y., Wang, J., Oh, D.-H., & Han, R. (2023). Marination ingredients on meat quality and safety—a review. *Food Quality and Safety, 7*. https://doi.org/10.1093/fqsafe/fyad027

Rattan, N., & Ramaswamy, H. (2014). *Effect of radio-frequency heating on food quality factors. Emerging Technologies for Food Processing*, 219-228. New York, USA: Academic Press. https://doi.org/10.1201/b17740-16

Rebezov, M., Chughtai, M. F. J., Mehmood, T., Khaliq, A., Tanweer, S., Semenova, A., Khayrullin, M., Dydykin, A., Burlankov, S., Thiruvengadam, M., Shariati, M. A., & Lorenzo, J. M. (2022). Novel techniques for microbiological safety in meat and fish industries. *Applied Sciences, 12*(1), 319. https://doi.org/10.3390/app12010319

Safdar, B., Zhou, H., Li, H., Cao, J., Zhang, T., Ying, Z., & Liu, X. (2022). Prospects for plant-based meat: Current standing, consumer perceptions, and shifting trends. *Foods, 11*(23), 3770. https://doi.org/10.3390/foods11233770

Sanchez-Sabate, R., & Sabaté, J. (2019). Consumer attitudes towards environmental concerns of meat consumption: A systematic review. *International Journal of Environmental Research and Public Health, 16*(7), 1220. https://doi.org/10.3390/ijerph16071220

Sethi, S., & Singh, M. (2021). Advances in alternative protein sources. *Food Science and Technology, 12*, 78–89.

Siegrist, M., & Hartmann, C. (2020). Consumer acceptance of novel food technologies. *Nature Food, 1*(6), 343–350. https://doi.org/10.1038/s43016-020-0094-x

Silva, A. B., Santos, C. D., & Oliveira, E. F. (2024). The impact of consumer skepticism on the perceived value of organic food and purchase intention. *Revista de Administração da UFSM, 17*(2), e985505. https://doi.org/10.5902/1983465985505

Silva, E. M., Lemos, M. V. A., dos Santos, B. A., Campagnol, P. C. B., Cichoski, A. J., & Wagner, R. (2019). Reducing 50% sodium chloride in healthier jerked beef: An efficient design to ensure suitable stability, technological and sensory properties. *Meat Science, 152*, 49–57. https://doi.org/10.1016/j.meatsci.2019.02.005

Simonin, H., Duranton, F., & de Lamballerie, M. (2012). New insights into the high-pressure processing of meat and meat products. *Comprehensive Reviews in Food Science and Food Safety, 11*(3), 285–306. https://doi.org/10.1111/j.1541-4337.2012.00184.x

Skandamis, P. N., & Nychas, G.-J. E. (2002). Preservation of fresh meat with active and modified atmosphere packaging conditions. *International Journal of Food Microbiology, 79*(1-2), 35–45. https://doi.org/10.1016/S0168-1605(02)00177-0

Sohail, A., Al-Dalali, S., Wang, J., Xie, J., Shakoor, A., Asimi, S., Shah, H., & Patil, P. (2022). Aroma compounds identified in cooked meat: A review. *Food Research International, 157*, Article 111385. https://doi.org/10.1016/j.foodres.2022.111385

Stephens, N., Silvio, L. D., Dunsford, I., Ellis, M. J., Glencross, A., & Sexton, A. (2018). Bringing cultured meat to market: Technical, socio-political, and regulatory challenges in cellular agriculture. *Trends in Food Science & Technology, 78*, 155–166. https://doi.org/10.1016/j.tifs.2018.04.010

Taormina, P. J. (2021). *Microbial growth and spoilage*. In Taormina, P. J., & Hardin, M. D. *Food safety and quality-based shelf life of perishable foods*. Springer Publishing House. https://doi.org/10.1007/978-3-030-54375-4_3

Tao, Y., Sun, D. W., Hogan, E., & Kelly, A. L. (2016). High-pressure processing of foods: An overview. In D.-W. Sun (Ed.), *Emerging technologies for food processing* (2nd ed., pp. 3–24). New York, USA:

Academic Press. https://doi.org/10.1016/B978-0-12-411479-1.00001-2

Teixeira, A., & Rodrigues, S. (2021). Consumer perceptions towards healthier meat products. *Current Opinion in Food Science, 38*, 147–154. https://doi.org/10.1016/j.cofs.2020.12.004

Weiß, J., Gibis, M., Schuh, V., & Salminen, H. (2010). Advances in ingredient and processing systems for meat and meat products. *Meat Science, 86*(1), 196–213. https://doi.org/10.1016/j.meatsci.2010.05.008

World Health Organization. (2021). *Diet and health in the 21st century: Addressing diet-related chronic diseases*. WHO.

Xiong, Y. L. (2022). The difference between microwave heating and radiofrequency heating [Diagram]. In *Chemical and Functional Properties of Food Components* (5th ed.). Asterdam, NL: Elsevier Publishing House. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/B9780323854085000194