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Review

Strategies for Healthier Meat Foods: An Overview

Cindy Espinales[1], María Baldeón[1], Cinthya Bravo[1], Howard Toledo[1], José Carballo[2], María Romero-Peña[1,3], and Patricio J. Cáceres[1]

[1]Facultad de Ingeniería en Mecánica y Ciencias de la Producción, Escuela Superior Politécnica del Litoral (ESPOL), Guayaquil EC090112, Ecuador
[2]Institute of Food Science, Technology and Nutrition (ICTAN-CSIC), Madrid 28040, Spain
[3]Saskatchewan Food Industry Development Centre (SFIDC), Saskatoon S7M 5V1, Canada

ABSTRACT: Functional food products remain the focus of current market trends toward healthier nutrition. The consumption of meat-based functional foods has been a topic of interest in food innovation since some of these products generate controversy due to their possible adverse effects on health. However, studies have demonstrated that meat-based functional products are considered an opportunity to improve the nutritional profile of meat products through the addition of biologically valuable components and to meet the specific needs of consumers. In this sense, some strategies and techniques are applied for processing and developing functional meat products, such as modifying carcass composition through feeding, reformulating meat products, and processing conditions. This review focuses on presenting developed and evaluated strategies that allow the production of healthy and functional meat foods, which application has successfully achieved the sensory, nutritional, and technological parameters mainly affected by such application.

Keywords: consumer behavior, food technology, functional foods, meat products, nutritional requirements

INTRODUCTION

Consumers are increasingly concerned about the relationship between diet and health, which influences their choice to buy and consume functional or healthier foods (Nazir et al., 2019). Red meat and meat products are good sources of nutrients, such as high-quality proteins (e.g., essential, and nonessential amino acids), fatty acids, and various micronutrients, including iron, zinc, selenium, vitamin D, and B_{12} (Salter, 2018). However, excessive consumption of these products is associated with an increased risk of chronic diseases, such as diabetes, cancer, cardiovascular disease, and obesity, which has been linked to their saturated fatty acids and cholesterol contents (Geiker et al., 2021). Reducing meat consumption has been associated with a decreased risk of developing various chronic diseases (Salter, 2018). Nonetheless, maintaining a moderate intake of meat remains crucial as it represents a key strategy for obtaining essential nutrients.

Meat products are useful matrices for the addition of different bioactive compounds for the development of functional foods and to reduce the unfavorable effects related to disproportionate meat intake, such as the high consumption of saturated fatty acids (Macho-González et al., 2021). Incorporating functional ingredients could benefit human health while meeting consumer expectations for nutritionally enhanced meat products (Manassi et al., 2022). Several studies have shown promising results for the reformulation of meat products to decrease the content of nitrites (Ferysiuk and Wójciak, 2020) and inorganic phosphates (Câmara et al., 2020) or to add a percentage of dietary fiber (Younis et al., 2022), and natural antioxidants (Niu et al., 2021). Pires et al. (2020), examined the use of echium oil and chia flour instead of pork and beef back fat in Bologna-type sausages. This substitution led to enhancements in the lipid profile, particularly through augmentation of the ω-3 content. This approach is a suitable method for enhancing the nutritional value of meat products.

In addition, researchers have actively replaced synthetic antioxidative agents with natural antioxidants because of their high phenolic and other active ingredient contents (Alirezalu et al., 2020). The research conducted by Suniati and Purnomo (2019) explored the use of Goroho banana flour as a natural antioxidant to replace tapioca flour in the production of Indonesian meatballs. The study had

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Correspondence to Patricio J. Cáceres, E-mail: pcaceres@espol.edu.ec

positive outcomes: substituting 50% and 100% of the tapioca flour with banana flour resulted in improved antioxidant capacity and higher phenol and tannin contents in the meatballs. These changes contributed to a delay in lipid oxidation and extended the shelf life of the final product. However, developing such meat products while preserving their sensory qualities and nutritional value represents a considerable challenge (Saldaña et al., 2021).

While several studies have highlighted the importance of employing effective techniques to develop functional meat products considering the processing and preservation techniques, only a limited number of studies have gathered comprehensive knowledge about these strategies. This includes aspects such as selecting suitable substitutes in the formulation and identifying the appropriate feed ingredients for the animal while maintaining the food's health-promoting functions and sensory attributes. Therefore, this review aims to identify and synthesize the advancement and potential applications of these strategies, including some novel technologies regarding the aspects evaluated for conserving sensory characteristics and nutritional availability in meat products. In addition, brief information concerning the potential health benefits and challenges related to the development of functional meat products is provided.

MATERIALS AND METHODS

This overview presents the literature published between 2017 and 2022. This study is based on a comprehensive review of information from three prominent scientific databases: Scopus (available at Reed Elsevier's website: https://www.scopus.com), Springer (accessible at https://www.springer.com), and the Multidisciplinary Digital Publishing Institute (found at https://www.mdpi.com). The articles were based on current scientific data on the strategies and techniques applied to achieve healthier meat products. The review explores a range of studies examining the modification of carcass composition through specialized feeding, the reformulation of meat products, and the optimization of processing conditions to provide pertinent insights into the implemented and evaluated strategies.

RESULTS AND DISCUSSION

Perspective of the meat industry and the conceptions of meat consumption

Worldwide trends in consumption are pointing toward healthier food products that must provide positive effects on health after their intake besides their nutritional value (Banwo et al., 2021). Moreover, consumers demand foods that have undergone minimal processing, such as fresh or frozen products, because of the biological value dependence on the processing conditions (Fiolet et al., 2018). Processed or ultra-processed foods, such as sausages, ham, canned meat, and hot dogs, have been associated with cancer because they contain food additives such as sodium nitrite or titanium dioxide (Srour et al., 2019). Consequently, some consumers have switched to plant-based products and reduced meat consumption (Kwasny et al., 2022).

Alternatively, with population growth, a considerable increase in the demand for animal protein has been predicted by 2050, with pork being the most consumed meat, followed by chicken, beef, and lamb (Lynch et al., 2018). Despite a challenging 2020, global meat production remained stable even for the world's largest meat exporters, who exported more meat in 2020 than in 2019 (FAO, 2021). Meat production in 2025 is estimated to increase by 16% compared with its production during 2013∼2015. In addition, over the last 50 years, meat consumption has increased from 61 g per person per day in 1961 to 80 g in 2011 (OECD and FAO, 2018). The growing market within the meat industry indicates greater chicken and poultry production. However, in developed countries, the products with the highest demand (representing more than half of the meat catalog products) are hamburgers, sausages, and meatloaf (Lynch et al., 2018).

From a public health perspective, the World Cancer Research Fund affirms that consumers in industrialized countries exceed the recommended nutritional intake of red and processed meat (Kwasny et al., 2022). The World Health Organization emphasizes the importance of balancing the consumption of meat products based on the results of several epidemiological studies that relate meat consumption with the incidence of chronic degenerative diseases (Caprara, 2018). This relationship has been widely studied, although more evidence is required to prove that meat consumption increases the risk of developing colorectal cancer (Mensah et al., 2022).

Developing functional meat products

Trends toward healthier products have given rise to functional foods, which are based on reducing undesirable components formed during processing and simultaneously increasing the beneficial effects on the consumer's health by using compounds with biological value (Guiné et al., 2020). Advances in healthy meat products have been achieved by adding compounds with specific benefits to a target audience with health issues such as cardiovascular disease (Pogorzelska-Nowicka et al., 2018). In addition to the adverse health effects of excessive consumption of processed meat products, meat is rich in bioactive components such as zinc, conjugated linoleic acid, iron, and B vitamins (Pogorzelska-Nowicka et al., 2018;

Collier et al., 2021) and their essential unsaturated fatty acid content contributes to nutrition and human health (Ahmad et al., 2018).

Functional meat product development has been achieved by applying strategies to improve the number of beneficial compounds present in meat (Terry et al., 2021). The primary method for designing functional meat products was described by Macho-González et al. (2021). The strategies include increasing a component already present in the food, adding a component not present in the food, eliminating a harmful element in the food, substituting a harmful component for a healthier one, increasing the bioavailability of the added ingredient or bioactive substance, and mixing some or all of these strategies. Depending on the product, it is possible to modify the composition of the food by identifying the components that can be replaced, reduced, or added.

According to several studies, the most suitable phase for modification is the preparation phase, where reformulation is ideal for developing a range of derived products with known compositions and properties (Ruiz-Capillas and Herrero, 2021). The lipid and fatty acid content can be modified and/or functional ingredients such as fiber, vegetable proteins, monounsaturated or polyunsaturated fatty acids, vitamins, minerals, and phytochemicals can be added; even whole foods such as walnuts or seaweed can be incorporated (Macho-González et al., 2021). Numerous studies have provided evidence that modifying livestock through dietary and genetic manipulation is another effective strategy because of its influence on the nutrient composition variation of meat products (Juárez et al., 2021).

Modification of carcass composition through nutritional and genetic strategies

Livestock practices are the first way to improve the biological value of meat and meat products (Chikwanha et al., 2018). The meat components of interest can be modified through feeding or genetic manipulation of the animal; this strategy demonstrates functionality with the contents of lipids, vitamins, and minerals (Juárez et al., 2021).

***Nutritional strategies*:** Changing the lipid profile of meat has been a topic of interest over the past few decades. This can be accomplished through breed selection (Cafferky et al., 2019) or modification of cattle feeding by incorporating probiotics (Al-Shawi et al., 2020), fatty acids (Davis et al., 2022), or dietary nutrients such as vitamins and trace elements (Juárez et al., 2021). Improvements in cattle feeding and technological advances have allowed the development of diets rich in fats that provide a balanced ratio of polyunsaturated fatty acids and ω-6/ω-3 fatty acids (Liput et al., 2021). Oils with high percentages of monounsaturated fatty acids, such as canola oil and fish oil, are added to the animal diet to increase the source of oleic acid (C18:1 n-9), which has been linked to vital cellular processes involving oxidative phosphorylation and cell growth (Almeida et al., 2021).

According to a study by Correa et al. (2022), incorporating canola oil into the diet of Nellore cattle resulted in increased levels of unsaturated fat, ω-3, and conjugated linoleic acid in their meat. This led to an improved ω-6/ω-3 ratio and reduced the saturated fat content. Animals supplemented with 3% canola oil exhibited enhanced liver antioxidant status, lowered cholesterol levels in the longissimus thoracis muscle, increased high-density lipoprotein (HDL) cholesterol in the blood serum, and decreased levels of substances reactive to 2-thiobarbituric acid. The effect obtained with canola oil supplementation is associated with the antioxidants that are present (e.g., selenium and vitamin E), which are related to changes in cholesterol metabolism by the increased HDL cholesterol fraction in the blood (Khalifa et al., 2021). Canola oil supplementation in cattle diets is considered a potential strategy to provide healthier meat for human consumption, resulting in a better lipid profile than that found in beef meat, with higher ω-3 and lower cholesterol contents (Correa et al., 2022).

Reducing cholesterol and saturated fatty acids in meat for human consumption by incorporating vitamins and minerals, such as vitamin E and selenium, in cattle diets has also been a topic of interest for market and public health benefits (Sun et al., 2019; Surai et al., 2019). Several studies have alleged that vitamin E supplementation is essential for all animal species because of its antioxidant activity, which can protect cell membranes, thereby preventing peroxidative fat degradation in animal cells and the formation of free radicals (Mansour-Gueddes and Saidana-Naija, 2021; Salles et al., 2022). In a study by Silva et al. (2020), supplementation with organic and inorganic selenium was examined in Nellore cattle. Dietary inclusion of organic selenium resulted in a higher concentration of this mineral in meat cattle, specifically in the latissimus dorsi muscle. Moreover, the selenium source influenced the oxidative stability: animals that received inorganic selenium had a higher percentage of thiobarbituric acid reactive substances, 15.51% higher than those supplemented with organic selenium (Silva et al., 2020).

Therefore, providing good nutrients, including trace minerals or vitamins, is necessary to meet the requirements of beef cattle and thus obtain maximum growth yield and better profitability for producers (Lee et al., 2020). Various methods exist for supplementing animal diets with trace minerals. In feedlot production systems, dietary supplementation is frequently employed to provide trace elements (Harvey et al., 2021). However, because of fluctuations in feed consumption, it cannot be guaranteed that animals will consistently receive the intended amounts of trace elements (Kırkpınar and Açıkgöz, 2018). Different methods of providing trace elements in a diet have different absorption rates and distinct production and health responses, such as providing trace elements through a rumen bolus (Goff, 2018). The advantage of the rumen bolus is that the animals receive similar amounts of trace elements; therefore, variation from one animal to another will be minimized (Hristov et al., 2019). The intake of trace elements through a bolus gives the animal a better carcass quality and optimal performance, especially during the finishing phase (Lee et al., 2020).

The addition of antioxidants to the animal diet has been considered as a strategy to increase the basal values of the lipid profile, optimizing the production of healthy meat, and providing economic benefits in the form of the prevention or reduction of antibiotics to combat diseases (Seidavi et al., 2022). Feeding a diet rich in antioxidants reduces the oxidation processes of cells. It prevents oxidative stress related to the appearance of diseases in farm animals (Corrêa et al., 2021). Meat quality is reflected in its color when it does not undergo oxidation reactions but provides nutritional improvement to the consumer (Cucci et al., 2020). Therefore, adding antioxidants to ruminant diets could be a valuable tool for preventing oxidative stress, which affects animal welfare and immune-related disease development (Mu et al., 2020; Elolimy et al., 2021).

Wen et al. (2022) studied the effects of dietary lycopene supplementation on the meat quality of finishing pigs. The results demonstrated that dietary supplementation with 200 mg/kg of lycopene improved meat color, nutritional value, and juiciness after slaughter. Modzelewska-Kapituła et al. (2018) reported a significant effect of herbal extract diet supplementation on the meat quality of 24 Holstein-Friesian bulls, referring to their proximate composition, technological properties, and sensory attributes.

The findings agreed with Tayengwa et al. (2020), who fed Angus steers 150 g/kg of dried citrus pulp and grape pomace as a dietary supplement for 90 days and evaluated their effect on meat quality and shelf life. The findings indicated that feeding steers with dried grape pulp improved the shelf life of beef during retail display by enhancing the antioxidant activity and reducing coliform and lipid and protein oxidation compared with dried citrus pulp and control diets (Tayengwa et al., 2020). Several studies have shown that animal nutrition is essential for regulating the biological processes of muscles, such as muscle protein turnover (Modzelewska-Kapituła et al., 2018). Incorporating certain compounds into cattle diets is a suitable strategy for reducing oxidative damage in meat tissue; oxidative damage leads to a decrease in meat quality, including its sensory attributes, technological properties, and nutritional value (Tayengwa et al., 2020).

***Genetic strategies*:** In addition to mineral and vitamin supplementation, various genes, and enzymes responsible for variation in cattle breeds are involved in fatty acid synthesis and fat deposition in cattle (da Silva Martins et al., 2018). There is extensive interest in manipulating the lipid metabolism of meat by understanding the effects of diet and gene expression, an association known as nutrigenomics (Nowacka-Woszuk, 2020). de Lima et al. (2020) conducted a study to examine the impact of feed efficiency on 180 Nellore cattle by investigating potential gene expression. The findings indicated that certain hub genes are active in the skeletal muscle of Nellore steers and influence traits related to feed efficiency. These genes play a crucial role in muscle protein synthesis, energy balance, and immune responses (de Lima et al., 2020). The authors argued that genetic analyses contribute to a deeper understanding of the biological mechanisms underlying feed efficiency in bovines, as well as the identification of the hub genes involved. However, there is limited literature available on the genetic associations specifically related to the high efficiency of feed use, which primarily relies on phenotypic information (Madilindi et al., 2022).

In addition to genetic strategies, aging has become a viable technique for improving the sensory attributes of meat because tenderization occurs over time, making the meat more tender after slaughter (Monteiro et al., 2022). Momot et al. (2020) determined the effects of bovine genotype and slaughter age on the mineral content and fatty acid profile of meat. The results showed that the intramuscular fat content of the longissimus thoracis muscle increased by up to 1.80% with age. The slaughter age significantly affected the concentrations of saturated, monounsaturated, and unsaturated fatty acids as well as the monounsaturated/saturated fatty acid ratio in bull longissimus thoracis muscles (Momot et al., 2020). Table 1 summarizes the approaches used to obtain healthier meat.

Meat products: reformulation

The strategies followed by the food industry are concerned with product reformulation by adding health-enhancing ingredients and limiting undesirable components (de Souza Paglarini et al., 2018). Two possible approaches can be applied through reformulation: reducing the harmful components present in these products, such as nitrites and phosphates, or incorporating ingredients that are potentially beneficial to health, such as dietary fiber, probiotics, monounsaturated and polyunsaturated fatty acids, and antioxidants (Ursachi et al., 2020).

***Incorporating natural antioxidants*:** The scientific literature contains various pertinent studies that propose to take advantage of the multiple bioactive components of fruits and vegetables to design processed meat products with enhanced nutritional and safety properties (Estévez, 2021). Healthy ingredients, such as walnut leaf, are known for

Table 1. Approaches for the development of healthier meat

Host	Population (n)	Dosage	Feeding ingredient	Duration (d)	Objective	Result	Reference
Male pigs	96	3%	Fish oil	98	Reduce fat and improve lipid profile	High quality meat with the highest content of ω-3 polyunsaturated fatty acids	Almeida et al., 2021
Nelore bulls	48	3% 2.5 mg/kg of dry matter 500 UI of vitamin E/kg	Canola oil Selenium Vitamin E	84	Improve lipid profile	Increased unsaturated fatty acids and ω-3 and linoleic acid levels Decreased saturated fat Improved the ω-6/ω-3 ratio	Correa et al., 2022
Nelore bovine	63	0.3, 0.9, and 2.7 mg Se/kg of dry matter	Organic selenium	84	Increase mineral content of meat	Reduced thiobarbituric acid reactive substances Higher selenium concentration in meat	Silva et al., 2020
Lambs	48	10, 20, and 40 mg/kg of dry matter	Grape seed extract	45	Improve liver function, growth performance and meat quality in the longissimus dorsi muscle	Increased the total antioxidative capacity, catalase, glutathione per-oxidase, and superoxide dismutase activity in the longissimus dorsi muscle	Mu et al., 2020
Finishing pigs	18	100 and 200 mg/kg	Lycopene	70	Improve meat quality	Increased muscle redness intramuscular fat, crude protein contents, and juiciness of pork after slaughter	Wen et al., 2022
Holstein-Friesian bulls	24	20, 40 g/animal/d	Herbal extracts (optirum and stresomix)	150	Improve meat quality	Beneficial technological properties and sensory tenderness of longissimus lumborum muscles	Modzelewska-Kapituła et al., 2018
Angus steers	24	150 g/kg	Grape pomace pulp	90	Extent shelf-life	Enhancement of antioxidant activity and reduction of coliforms, lipid, and protein oxidation	Tayengwa et al., 2020

their hypoglycemic effects because of their active components (Liu et al., 2020). Boruzi and Nour (2019) evaluated the effects of adding walnut leaf powder on the functional and physicochemical properties of pork patties that were refrigerated for 15 days without any additional technological processes. The results showed that the addition of 0.5% walnut leaf powder to cooked pork patties was more effective in reducing the lipid oxidation effect during 15 days of storage than the addition of 0.1% butylhydroxytoluene (BHT) (Boruzi and Nour, 2019).

Regarding reformulation and the addition of antioxidants to meat products, other authors have presented the incorporation of pomegranate peel. Numerous studies have demonstrated interest in this by-product as a nutritional or medicinal product because of its high levels of polyphonic compounds, which are attributed to its powerful antifungal properties as an alternative to synthetic antioxidants (Smaoui et al., 2021). Ghimire et al. (2022) studied the performance of aqueous pomegranate peel extract (1% and 1.5%) of the Ganesh variety as a natural antioxidant in ground buffalo meat during storage at 4°C. The extracts presented significant antioxidant activity in buffalo ground meat regarding peroxide and thiobarbituric acid reactive substance values and conferred a considerable reduction in antimicrobial activity regarding the total plate counts compared with 0.01% BHT and the control sample (Ghimire et al., 2022). Morsy et al. (2018) obtained similar results regarding antioxidant and antimicrobial activity by incorporating lyophilized pomegranate peel nanoparticles (1% and 1.5%) into beef meatballs.

The incorporation of herbal extracts such as green and black tea (*Camellia sinensis L.*) extracts as natural antioxidants in meat products has also been extensively studied. For example, Jayawardana et al. (2019) evaluated the antioxidant effect of green and black tea extracts in uncured pork sausages during a 5-day storage period and obtained favorable results with both extracts. The incorporation of black tea extract (0.05% and 0.3%) and 0.05% green tea extract was found to reduce the thiobarbituric acid reactive substances in uncured pork sausages without altering the sensory characteristics. Similarly, Wojtasik-Kalinowska et al. (2021) determined the effects of the addition of 1% *C. sinensis* L. on the lipid oxidation and sensory properties of beef and pork meatballs stored at −18°C for 0, 14, 28, 42, and 90 days compared with the effects of the addition of 0.01% BHT. The effectiveness of the extract from *C. sinensis* L. on the oxidative stability after 90 days of frozen storage was twice as high as that of the control group, which extended the shelf life and improved consumer acceptability. In this regard, the meat industry has used antioxidant compounds to both reduce oxidation processes and inhibit the growth of microorganisms (Ferysiuk and Wójciak, 2020). Incorporating bioactive ingredients in the formulation of meat products increases shelf life and preserves quality during processing and storage. It also contributes to the product's functional properties (Gullón et al., 2020).

***Reducing salt levels and sodium nitrite content*:** Given the increased interest in the incorporation of plant-based ingredients due to their functional properties, marine macroalgae are another excellent source of biocompounds such as polysaccharides, protein, ω-3 fatty acids, carotenoids, phenolic compounds, vitamins, and minerals (Cikoš et al., 2018). This large number of active compounds has encouraged researchers to design seaweed-based functional foods, including meat products, to help prevent disease and reduce the risk of chronic illnesses (Gullón et al., 2020). Seaweeds have high mineral content that offers the opportunity to design low-salt meat products with health benefits, reducing sodium consumption while improving the intake of other minerals (Gullón et al., 2021). In this regard, Vilar et al. (2020) investigated the impact of the inclusion of four selected red (*Porphyra umbilicalis* and *Palmaria palmata*) and brown (*Himanthalia elongata* and *Undaria pinnatifida*) seaweeds (1%) in reformulated frankfurters. The addition of seaweed reduced the salt and pork fat content by 50% and 21%, respectively, compared with the control. The inclusion of *H. elongata* seaweed in reformulated frankfurters showed the most promising results for the formulation (Vilar et al., 2020). Brown seaweeds have been incorporated into meat products to reduce salt levels and sodium nitrite content because of their remarkable antioxidant properties (Ying et al., 2019). Sellimi et al. (2017) isolated a carotenoid called fucoxanthin, extracted from Tunisian brown seaweed (*Cystoseira barbata*), and incorporated it in cured meat sausages to reduce sodium nitrite levels. The addition of the carotenoid resulted in strong antioxidant and antihypertensive properties, reduced sodium nitrite levels (from 150 to 80 ppm), enhanced the meat's color stability during 15 days of refrigeration, and delayed lipid oxidation (Sellimi et al., 2017).

Several studies have been conducted to develop nitrite substitutes from vegetable powders, such as radish (Jeong et al., 2020a), beetroot (Ozaki et al., 2021), Chinese cabbage (Jeong et al., 2020b), celery (Pennisi et al., 2020), flaxseed and tomato powders (Ghafouri-Oskuei et al., 2020). The addition of vegetable powders has demonstrated successful results in terms of the quality properties and shelf-life stability of nitrite/nitrate, and they are therefore potential alternatives for developing healthier meat products.

***Incorporating natural emulsifiers*:** There is scientific enthusiasm for chia seeds, which are well known for their physicochemical and functional properties and have revealed great technological potential for meat product development (Fernández-López et al., 2021). Chia flour has high emulsifying activity, which is sufficient to provide high emulsion stability and gelling properties, contributing to the maintenance of the protein network and the continuous phase in the meat emulsion (Fernández-López et al., 2019). In this context, Câmara et al. (2020) evaluated the functional properties of chia mucilage powder and gel (2% and 4%) as phosphate substitutes in low-fat Bologna sausages. The results showed that 2% chia mucilage gel provided better emulsion stability and overall acceptance because of its functional properties. It has been proven feasible to substitute 50% phosphate with chia mucilage gel in low-fat Bologna sausages (Câmara et al., 2020).

The use of different vegetable oils with other protein/starchy ingredients, such as pseudocereal flours, has also been studied for the stability of oil-in-water (O/W) emulsions (Fernández-López et al., 2021). Pintado et al. (2018) presented an interesting approach to evaluate the effect of incorporating O/W emulsion gels using chia and oat flour with olive oil as animal fat replacers in reduced-fat fresh sausages during chilled storage (18 days at 2°C). Sausages reformulated with chia and oat emulsion gels had improved fat contents, with high levels of monounsaturated fatty acids and reduced saturated fatty acids. However, the addition of chia and oat gels affected specific technological properties such as water and fat binding properties, sensory characteristics, and texture profile (Pintado et al., 2018). Incorporating vegetable oils directly can affect the binding capacity and stability of the meat protein matrix, thereby diminishing the textural quality (Chen et al., 2020). In this sense, pre-emulsification of unsaturated oils has appeared as an acceptable method for improving the emulsion stability and lipid profile to compensate for the impacts of animal fat without diminishing the technological quality (Bolger et al., 2018). Urgu-Öztürk et al. (2020) incorporated pre-emulsified hazelnut oil (0%, 50%, and 100%) and hazelnut powder (0%, 3%, and 6%) into sausage formulations as beef fat substitutes to determine the impacts on the lipid profile and the sensory and oxidative properties during 60 days of storage at 4°C. Partial or total replacement of beef fat with pre-emulsified hazelnut oil plus hazelnut powder not only decreased the saturated fat content and increased the unsaturated fat content but also resulted in sausages with textural, sensory, and technological qualities equivalent to those of commercial sausages (Urgu-Öztürk et al., 2020).

Therefore, the meat industry has many new opportunities for developing functional meat products by considering reformulation with plant-based ingredients that have functional and technological properties. Recent reformulation approaches in meat products have assisted the design of healthier products without a decrease in quality and are strongly influenced by sustainability and safety alternatives. However, the application of conventional techniques for developing and preserving healthier meat products should also be considered primarily for quality attributes and heat-sensitive compound loss risk (Sandesh Suresh and Kudre, 2022).

***Adding natural fiber sources*:** Dietary fibers incorporated into meat product matrices have been linked to a reduction in the carcinogenic impact of meat by accelerating fecal transit through the colon and binding minerals to reduce heme activity (Younis et al., 2022). However, incorporating dietary fiber into meat products can result in textural alterations, with some fibers increasing hardness and others increasing softness, which is typically influenced by the composite nature of the fiber source (Younis et al., 2022). Research has been conducted to develop functional meat products using different types of fiber. In a study by (Bis-Souza et al., 2020b), the addition of fructooligosaccharides was evaluated in low-fat Spanish salchichón (dry-cured sausage), which resulted in a 29% reduction in fat content with no significant differences in the physicochemical and sensory characteristics. It has also been reported that this type of fiber improves the texture and water-holding capacity of meat products (de Sousa et al., 2020). Inulin is a natural oligosaccharide that possesses a high dietary fiber content and prebiotic properties, which have been examined for the technological and quality parameters of low-fat products, showing excellent results, including decreased cooking loss and improved emulsion stability (Keenan et al., 2014). These both prebiotic fibers, such as inulin and fructooligosaccharide, are capable to boost acetate and propionate concentrations, improving gut barrier integrity, inducing weight loss, and decreasing food intake, which make them a suitable option to be added in meat foods (Bis-Souza et al., 2020a). Table 2 summarizes the studies that have been conducted to obtain healthier meat products.

Processing and conditions of conservation and consumption

Different factors associated with processing, conservation, and consumption conditions can result in harmful compounds or biological values (Rebezov et al., 2022). Possible alterations in the density variation of some substances, such as nitrosamines and polycyclic and biogenic amines, can affect the taste of the meat or have harmful health consequences (Flores et al., 2019). Although present in a wide variety of meat products, these compounds are considered carcinogenic and are mainly produced from chemical reactions between the nitrifying agents and secondary amines present in the complex matrix. These compounds may be influenced by many factors, such as nitrite content, degree of protein oxidation, and processing methods, such as fermentation and curing (Lu et al., 2022).

***Fermentation*:** Microorganisms contribute to the formation of nitrosamines in response to metabolic reactions, including the passage from nitrate to nitrite; they also contribute to the formation of enzymes that catalyze these reactions (Flores and Toldrá, 2021). However, under fermentative conditions, microorganisms such as *Lactobacillus* spp. can be incorporated to naturally inhibit the formation of nitrosamines by reducing nitrite residues and inhibiting the accumulation of biogenic amines (Xiao et al., 2018). Studies have been conducted on products such as sausages isolated with *Lactobacillus pentosus*, which present a decrease in the amine content due to the competitiveness of the dominant microorganisms. The metabolites produced by *L. pentosus* inhibit the growth of pathogens that contribute to the production of nitrosamines (Xiao et al., 2018). The study conducted by Kęska and Stadnik, (2018) agreed with adding probiotics to dry-cured pork meat to increase the peptide content and antioxidant activity in meat products and considered fermentative processes in combination with thermal treatment as an alternative to reduce the concentration of histamine (Visciano et al., 2020).

***Cold plasma*:** Nonconventional and nonthermal treatments, such as cold plasma technology, have also been applied for food preservation. This technology involves the collection of various atomic, molecular, ionic, and radical species that coexist with other molecules in the grounded or excited state (Misra et al., 2018). The treatment of cold plasma has the effect of arresting enzyme activity and pathogenic microorganisms due to the sterilizing activity of plasma and the ionized state of the plasma gas (Misra et al., 2019), thus helping to increase the shelf life of products (Jadhav and Annapure, 2021). This method has been effectively used in food and water-based liquids, known as plasma-activated water (PAW), to change their physicochemical characteristics, such as pH and electrical conductivity (Sandesh Suresh and Kudre, 2022). The application of PAW as a brine solution in beef jerky was studied by Inguglia et al. (2020), who examined the increase in nitrogenous compounds, such as nitrates, to explore the antimicrobial effects. The results showed that there were no significant differences in the texture and lipid oxidation of the jerky compared with the control samples, although the color was redder than the control. Therefore, the application of PAW was demonstrated to be a successful strategy for microbiological decontamination (Inguglia et al., 2020).

This nonthermal technology has also shown potential application in preserving packaged food products against pathogenic microbes, offering antimicrobial treatment for food already sealed in packages (Gao et al., 2021; Jadhav and Annapure, 2021). For example, Bauer et al. (2017)

Table 2. Approaches for developing healthier meat products

Strategy	Meat product	Ingredient added	Percentage added (%)	Replaced/reduced ingredient	Result	Reference
Replacing synthetic components	Cooked pork meat patties	Walnut leaf powder	0.2 and 0.5	BHT (0.1%)	Walnut at 0.5% in cooked pork patties was more effective than 0.1% BHT in reducing the lipid oxidation	Boruzi and Nour, 2019
	Ground buffalo meat	Ganesh pomegranate peel extract	1 and 1.5	BHT (0.01%)	Improved the preservation under storage at 4°C. Higher content of polyphenols and antioxidant activity. Lower Thiobarbituric acid reactive substances values	Ghimire et al., 2022
	Pork sausages	Green and black tea extracts	0.05, 0.10, 0.20, and 0.3	BHT (0.1%)	Reduction of thiobarbituric acid reactive substances values. Overall acceptability (color, odor, texture, juiciness, and taste)	Jayawardana et al., 2019
	Meatballs	Green tea extract	1	BHT (0.01%)	Oxidative stability after 90 days of frozen storage. Extended shelf-life. Improved acceptability	Wojtasik-Kalinowska et al., 2021
	Fermented dry sausages	Radish powders	0.5 and 1	Sodium nitrite and sodium nitrate (150 mg/kg)	Accomplished nitrite and nitrate substitution, regarding pH, color, and lactic acid bacteria development	Ozaki et al., 2021
Reducing synthetic components	Frankfurters	Brown edible seaweeds	1	Salt (NaCl) 50% Fat 21%	Improved the nutritional quality through mainly salt reduction. Significant differences in sensory and textural attributes	Vilar et al., 2020
	Turkey meat sausages	Lyophilized *Cystoseira barbata* seaweed	0.2 and 0.4	Sodium nitrite (70 ppm)	Inhibitory microbial effect and retarded lipid oxidation	Sellimi et al., 2017
	Beef sausages	Tomato powder Flaxseed powder	3	Sodium nitrite residue	Increased of Linolenic acids, lycopene, protein, and fiber. Maintained sensorial characteristics on cooked and fried sausages	Ghafouri-Oskuei et al., 2020
	Low-fat Bologna sausages	Chia mucilage powder and gel	2	Phosphate (50%) Fat (50%)	Better emulsion stability and overall acceptance	Câmara et al., 2020
	Fresh sausages (*longaniza*)	Chia and oat emulsion gels	27	Fat (75%)	Improved monounsaturated and polyunsaturated fatty acids content. Increased minerals content and α linolenic acid	Pintado et al., 2018
	Beef sausages	Pre-emulsified hazelnut oil	50 and 100	Fat (50%)	Decreases saturated fats, and increases unsaturated fats	Urgu-Öztürk et al., 2020
		Hazelnut powder	3 and 6		Equivalent texture, sensory, and technological quality to standards	

BHT, butylhydroxytoluene.

reported favorable results with the application of atmospheric cold plasma in packed beef longissimus, which resulted in a log 2 reduction of inoculated *Staphylococcus aureus*, *Listeria monocytogenes*, and two *Escherichia coli* strains, without affecting the integrity of the packaging matrix. Gao et al. (2021) also reported a >50% reduction in microbial growth in chicken breast meat patties packed in a modified atmosphere and treated with cold plasma. This study demonstrated the effect of cold plasma on mesophilic inactivation and the synergy between antioxidants added to the food matrix and treatment to prevent oxidative damage (Gao et al., 2021).

***High-Pressure Processing (HPP)*:** HPP is another alternative nonthermal minimal processing technology. HPP is applied to meat for decontamination and has only a minor impact on its nutritional and sensory characteristics. HPP is one of the best food safety solutions against foodborne pathogens such as *Salmonella* spp., *E. coli*, and *L. monocytogenes* in meat products (Serra-Castelló et al., 2022). HPP inactivates foodborne pathogens and spoilage microorganisms, meeting the regulations demanded by the national food safety authorities of many countries. It can eliminate pathogenic microorganisms and achieve a log 3 or more reduction in microbial activity without modifying the properties of the food (Sehrawat et al., 2020). During HPP, the meat is subjected to a pressure range of 350～

600 MPa for a few minutes to reduce microbiological activity and enhance shelf life (Gómez et al., 2020). This treatment has great potential for meat products because it protects and improves the functional properties of myofibrillar proteins (i.e., production of peptides). Its application also significantly increases the solubility of meat proteins at low and normal pH levels when treated at 50 and 100 MPa (Chen et al., 2018). The meat industry can use the application of this food processing technology to produce novel, safe, innovative, high-quality, convenient, and ready-to-eat meat products that hold quality attributes for healthy, natural, and minimally processed meats (Bolumar et al., 2020; Sandesh Suresh and Kudre, 2022).

***Potential health benefits of functional meat products*:** Functional foods constitute an opportunity for the meat industry to improve the quality and perception of meat products. This will prevent market losses related to the negative perception of meat and achieve much-needed diversification in the sector's activity by developing products with health-beneficial properties (Liu et al., 2022). In this regard, people who suffer from serious diseases are not allowed to ingest meat derivatives because of their high-fat contents (Godfray et al., 2018). The replacement of animal fat with vegetable oils decreases the incidence of cardiac diseases because of their content of monounsaturated fatty acids (Heck et al., 2021). Reformulating meat products by adding vegetable oils can allow people to consume meat without representing a high risk to their health. Such is the case with the development of a new type of beef sausage, in which approximately 40% of the total fat was replaced by emulsion systems containing peanut and linseed oils, resulting in a better nutritional profile without affecting the sensory attributes of the product (Nacak et al., 2021).

Another meat product ingredient that must be reduced is sodium chloride (NaCl). NaCl is responsible for conferring a high risk of cardiovascular disease, especially in people who excessively consume NaCl from meat products (Kim et al., 2021). Although the addition of NaCl improves the solubilization of proteins, enhances flavor, and increases the shelf life of the food product, in some products, potassium chloride can be used as a substitute for NaCl to reduce sodium levels (Tan et al., 2022).

There is a growing interest in incorporating seaweeds (Vilar et al., 2020) instead of synthetic additives. The addition of functional compounds to meat products gives them advantages over conventional meat products. Incorporating seaweeds, a type of algae, in the formulation of meat products creates a source of biocompounds that offer health benefits due to their antioxidant capacity potential and their antihyperlipidemic, antihypertensive, and anticancer properties (Gullón et al., 2020). Algae can be incorporated in concentrations up to 40%, significantly reducing the microbial count (Wang et al., 2018). These marine ingredients contain high levels of vitamins, protein, minerals, and dietary fiber; however, their consumption is relatively low in Western countries despite being a product that can be easily purchased and at low cost (Gullón et al., 2020). The bioactive ingredients present in algae can give meat products functional properties, including antioxidant, neuroprotective, and antigenotoxic properties, resulting in healthier foods (Wang et al., 2023).

In the study conducted by Quitral et al. (2019), sausages with added algae had a low level of nitrites (up to 26% lower compared to conventional sausages) and maintained their physicochemical characteristics. Moreover, the partial or total substitution of nitrite in meat products has been investigated in several studies due to its detrimental effect on human health (Ferysiuk and Wójciak, 2020). Plant-based ingredients, as natural antioxidants, have been studied as a partial substitute for nitrite. However, their use has been limited due to alterations in the sensory and textural attributes of the food (Šojić et al., 2019). Nevertheless, the combination of natural antioxidants seems to be an effective way to maintain the sensory characteristics, product quality, and reduction in nitrite content (Šojić et al., 2020).

Conclusions

The association between meat consumption and chronic disease has sparked much debate, but meat production and distribution remain crucial for the global economy and food supply. This presents an opportunity for the development of healthy and functional meat products. Various studies have suggested approaches and guidelines for modifying meat composition through genetic engineering or livestock feeding by incorporating bioactive ingredients. Reformulating products with bioactive compounds such as unsaturated fatty acids, antioxidants, probiotics, and vitamins is also valuable. Processing and storage conditions, including innovative technologies such as HPP, can enhance the presence of biologically significant compounds. Evaluating the impact of processing, reformulation, and compositional changes is necessary to develop competitive strategies in the meat industry.

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AUTHOR CONTRIBUTIONS

Concept and design: CE, PJC. Writing the article: CE, MB, CB, HT. Critical revision of the article: JC, MRP, CE, PJC. Final approval of the article: all authors. Obtained funding: PJC. Overall responsibility: PJC.

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