Running title: Recent strategies for improving the quality of meat products

RECENT STRATEGIES FOR IMPROVING THE QUALITY OF MEAT PRODUCTS

Seonmin Lee[a], Kyung Jo[a], Seul-Ki-Chan Jeong[a], Hayeon Jeon [a], Yun-Sang Choi[b], and Samooel Jung[a,*]

[a] *Division of Animal and Dairy Science, Chungnam National University, Daejeon 34134, Korea*

[b]*Research Group of Food Processing, Korea Food Research Institute, Wanju 55365, Korea*

[*]All correspondence should be addressed to Dr. Samooel Jung

Division of Animal and Dairy Science, Chungnam National University, Daejeon 34134, Korea

Tel: +82-42-821-5774 Fax: +82-42-825-9754

Email: samooel@cnu.ac.kr

Abstract

Processed meat products play a vital role in our daily dietary intake due to their rich protein content and the inherent convenience they offer. However, they often contain synthetic additives and ingredients that may pose health risks when taken excessively. This review explores strategies to improve meat product quality, focusing on three key approaches: substituting synthetic additives, reducing the ingredients potentially harmful when overconsumed like salt and animal fat, and boosting nutritional value.

To replace synthetic additives, natural sources like celery and beet powders, as well as atmospheric cold plasma treatment, have been considered. However, for phosphates, the use of organic alternatives is limited due to the low phosphate content in natural substances. Thus, dietary fiber has been used to replicate phosphate functions by enhancing water retention and emulsion stability in meat products. Reducing the excessive salt and animal fat has garnered attention. Plant polysaccharides interact with water, fat, and proteins, improving gel formation and water retention, and enabling the development of low-salt and low-fat products. Replacing saturated fats with vegetable oils is also an option, but it requires techniques like Pickering emulsion or encapsulation to maintain product quality.

These strategies aim to reduce or replace synthetic additives and ingredients that can potentially harm health. Dietary fiber offers numerous health benefits, including gut health improvement, calorie reduction, and blood glucose and lipid level regulation. Natural plant extracts not only enhance oxidative stability but also reduce potential carcinogens as antioxidants. Controlling protein and lipid bioavailability is also considered, especially for specific consumer groups like infants, the elderly, and individuals engaged in physical training with dietary management.

Future research should explore the full potential of dietary fiber, encompassing synthetic additive substitution, salt and animal fat reduction, and nutritional enhancement. Additionally, optimal sources and dosages of polysaccharides should be determined, considering their distinct properties in interactions with water, proteins, and fats. This holistic approach holds promise for improving meat product quality with minimal processing.

Keywords: nitrite, phosphate, sodium chloride, animal fat, nutrition, meat product

Introduction

Meat products such as ham, sausage, and jerky are consumed worldwide because they not only supply high-quality proteins but are also convenient to use. As consumers demand high-quality meat products, various studies have been conducted to improve the quality properties of meat products [1,2].

Various quality factors are present in meat products and synthetic additives such as nitrites and phosphates are added to improve the quality of meat products [3,4]. Owing to consumer concerns regarding the health hazards of synthetic food additives, consistent efforts have been made to develop natural sources that can replace synthetic food additives [5-7]. Sodium chloride (NaCl) is an essential ingredient in meat products because it enhances flavor and solubilizes myofibrillar proteins, which is important for forming a gel that effectively holds water and fat as well as possesses the desired texture [6,8]. However, high sodium intake is considered a detrimental factor for health [9]. Therefore, the reduction of NaCl in meat products without deterioration of quality is required [10]. Fat is an important component in comminuted meat products. The addition of fat to comminuted meat products improves their flavor, juiciness, and texture [11]. However, the replacement of animal fat in meat products is required because the intake of animal fat containing high saturated fatty acids can lead to obesity and cardiovascular diseases [11-13].

Protein gels contain various compounds that can be used as carriers of them [14]. Therefore, enhancing the nutritional value of meat products by the addition of health-beneficial compounds has recently attracted attention. Many studies have attempted to replace synthetic additives, salts, and animal fat with natural sources that have substances beneficial to health as well as the function of each object [15-17]. In addition, researchers have attempted to control the digestibility of proteins and fats in meat products for improving the nutritional quality.

Therefore, the objective of this review was to report recent studies conducted to improve the quality of meat products. In addition, future research directions for improving the quality of meat products are discussed.

Replacement of synthetic additives

Various synthetic additives such as nitrite, phosphate, and antioxidants are used to produce meat products [3]. Among these, synthetic antioxidants have been effectively replaced by natural extracts containing phenolic compounds. In this review, we discussed the replacement of nitrite and phosphate in meat products.

Nitrite

Nitrite is a multifunctional additive used in meat products. The addition of nitrite to meat products results in a cured color and flavor, reduces lipid oxidation, and inhibits the growth of microorganisms, including *Clostridium botulinum* [18,19]. Generally, replacing synthetic nitrite with natural nitrite is required.

The general method for replacing synthetic nitrite is the use of extracts or homogenates of natural plants after the conversion of endogenous nitrate in plant to nitrite [18]. Various natural nitrite sources containing nitrate or nitrite (pre-converted from nitrate), such as celery, beet, and spinach powders, have been reported. However, there are reports of a lack of microbial safety in meat products containing natural nitrite sources [20]. The production of nitrite from natural sources is limited, because it is determined by the nitrate content of the plant. Therefore, a large amount of natural nitrite must be added to reach the level required to ensure the safety of meat products. However, the addition of natural nitrite sources in meat products is limited to preventing undesirable effects of plant flavor on the flavor of meat products [18-21]. Therefore, studies have been conducted to develop natural nitrite sources that have no undesirable effects on the sensory quality of meat products. Recently, arugula extract (pre-conversion of nitrate to nitrite) [1] and radish derivatives (pre-conversion of nitrate to nitrite) [23] were tested as natural nitrite sources in fermented sausage and restructured cooked ham, respectively. No undesirable effects on the sensory quality of meat products with a curing effect similar to that of sodium nitrite have been reported (Table 1) [1, 23].

A new concept using atmospheric cold plasma to replace synthetic nitrite has been reported [24,25]. Plasma is an ionized gas containing reactive oxygen and nitrogen species [26, 27]. The reactive nitrogen species in the plasma can produce nitrite by reacting with water molecules [28]. Therefore, atmospheric cold plasma has been used as a new technology to produce natural nitrite sources because nitrite can be generated in natural substances with plasma treatment, regardless of the nitrate content. Marcinkowska–Lesiak et al. [29] reported that plasma-activated milk powder (treated with cold plasma and then freeze dried) contains 1,306 ppm of nitrite. Pork sausages have been effectively cured using plasma-activated milk powder with reduced lipid oxidation, aerobic bacterial growth, and desirable sensory quality [29]. Jo et al. [17] also observed that 4,870 ppm of nitrite was generated in winter mushroom powder with cold plasma treatment, and ground ham cured by plasma-treated winter mushroom powder exhibited physicochemical properties similar to those of ground ham cured with sodium nitrite. Jo et al. [26] reported no toxicity in plasma-treated winter mushroom powders.

The curing molecule in meat products is nitric oxide degraded from nitrite via sequential chemical reactions [18]. In muscles, NO can be endogenously generated from l-arginine through the action of NO synthase. Luo et al. [30] observed that nitrosylmyoglobin, a pigment for cured color, was formed in pork batter after the addition of L-arginine and *Lactobacillus fermentum* and reported that it was caused by NO generation from L-arginine by the action of NO synthase in *Lactobacillus fermentum*. Liu et al. [31] reported that the activity of nitric oxide synthase continued for 3 d postmortem. In addition, nitrosylmyoglobin was formed in pork batter owing to ultrasound treatment because ultrasound treatment increased the calcium concentration in the cytoplasm and then activated calmodulin, which is a protein that activates NO synthase [32].

As explained above, various methods have been reported to replace synthetic nitrite, such as the use of natural nitrite sources, atmospheric cold plasma technology, and NO synthase systems. However, the antimicrobial activity of the reported methods as substitutes for synthetic nitrites has not been suggested (Table 1). An important role of nitrite in meat products is to control pathogenic bacteria, including *Clostridium botulinum*. Therefore, future studies on the development of synthetic nitrite substances should investigate their antimicrobial activities against pathogenic bacteria. However, care should be undertaken when using nitrite in meat products because it can form carcinogenic nitroso compounds [33]. Therefore, methods for inhibiting nitrosamine formation in meat products must be continuously developed.

Phosphate

Phosphates are multifunctional additives that are found in meat products. Various inorganic phosphates with chain structures are permitted in the manufacturing of meat products. Although acidic phosphates, such as sodium acid pyrophosphate ($Na_2H_2P_2O_7$), can be used as curing accelerators, the most phosphate used in meat products are alkaline phosphates such as sodium pyrophosphate ($Na_4P_2O_7$) and sodium tripolyphosphate ($Na_5P_3O_{10}$) because of their multifunctional roles and relatively high solubility compared to other phosphates [34]. Although inorganic phosphates have low toxicity, an inorganic phosphate intake of less than 1,000 mg/day is recommended [35, 36].

Unlike nitrite, the use of organic phosphate to replace synthetic phosphate (inorganic phosphate) is limited, because natural substances possess low content of phosphate. Therefore, synthetic phosphate in meat products has been replaced by substances with functions similar to those of phosphate in meat products. Alkaline phosphates generally used in meat products improve the water-holding capacity, emulsion stability, textural properties, and oxidation stability by increasing pH, dissociating actomyosin, increasing ionic strength, and chelating metal ions [36].

Dietary fiber is considered an alternative to phosphate in meat products. Dietary fiber has excellent water- and fat-binding capabilities [37]. Therefore, it has been used to improve the water holding capacity and emulsion stability of phosphate-free meat products [6, 38]. Yuan et al. [38] found a decrease in cooking loss and an increase in emulsion stability with the inhibition of lipid oxidation in phosphate-free frankfurters with the addition of seaweed dietary fiber (Table 2). In addition, the addition of winter mushroom powder (44.5% dietary fiber) to phosphate-free beef patties resulted in a decrease in cooking loss and inhibition of lipid oxidation by increasing the pH of the batter and water and fat binding [6, 39]. However, the addition of dietary fiber sources as phosphate alternatives to meat products did not increase the solubility of myofibrillar proteins, which is an action of phosphate, and result in a decrease in the hardness of gel products [6, 17]. Therefore, methods are needed to improve the solubility of myofibrillar proteins and the formation of desirable gel structures in phosphate-free meat products using dietary fiber sources. Pinton et al. [40] used ultrasound treatment with bamboo fiber in a phosphate-free meat emulsion and found that the emulsion stability and textural properties were improved because of the improvement in water-holding capacity and the increase in myofibrillar protein solubility by a modification in the protein structure. In addition, Jeong et al. [2] reported that hot-boned pork had high solubility of myofibrillar protein, and pork gel manufactured using hot-boned pork and winter mushroom powder without phosphate showed quality properties similar to those of pork gel containing phosphate.

An activity of phosphate in meat products is a dissociation of actomyosin formed in the postmortem muscle [34, 41]. High-pressure treatment improves the solubility of myofibrillar proteins by dissociating actomyosin [41, 42]. Guan et al. [42] reported that the stability of pork emulsions was improved when high-pressure processing and soy protein isolate hydrolysates were used. However, Jeong et al. [43] reported that the strength of pork gel manufactured from pork treated with high pressure was lower than that of the gel containing phosphate, although the actomyosin content in pork and the solubility of myofibrillar proteins decreased and increased, respectively, with high-pressure processing at 200 MPa. A previous study found that phosphate in meat products not only increased solubilized proteins but also enhanced the stability of the gel structure through phosphate group-mediated interactions between proteins

[44]. Therefore, the low gel strength with low structural stability in meat gels may be caused by phosphate-free systems, although the water-holding capacity, emulsion stability, and protein solubility were improved using dietary fiber and techniques such as ultrasound and high pressure.

Reduction of the ingredients potentially harmful when overconsumed

NaCl

NaCl is an essential ingredient in meat products, especially comminuted meat products, because it provides desirable textural properties and flavor in gel products. The addition of NaCl to meat products increases their ionic strength and consequently solubilizes myofibrillar proteins [10]. Solubilized myofibrillar proteins act as emulsifiers and form aggregated elastic gels that effectively hold water and fat [45]. In addition, Cl^- increase net charges in myofibrillar proteins and increase the water-holding capacity of meat products [39]. Generally, an addition of NaCl at a level of 1.5–2.5% is required to obtain meat products of desirable quality. However, a high intake of Na^+ can cause various diseases, such as hypertension and cardiovascular damage [8]. Therefore, efforts to reduce Na^+ levels in meat products are ongoing. Many studies have investigated the effects of other chloride salts, such as potassium chloride (KCl), calcium chloride, and magnesium chloride as substitutes for NaCl in meat products. Among the chloride salts, KCl has similar properties to NaCl in terms of increased solubility of myofibrillar proteins and water-holding capacity in meat products [46]. However, the bitter taste of KCl limits its widespread applications.

Various quality factors, such as the solubility of myofibrillar proteins, water-holding capacity, emulsion capacity and stability, gel-formation capacity, salty flavor, and microbiological safety, deteriorate in low-salt meat products [39, 47]. Recently, plant polysaccharides have attracted attention as substances for improving the quality of low-salt meat products. Plant polysaccharides can be categorized into anionic, cationic, and neutral types based on their surface charges and can directly interact with water, fat, and proteins [48]. Gao et al. [49] observed that the addition of konjac glucomannan to low-salt myofibrillar protein gels increased gel strength by unfolding myofibrillar proteins and promoting disulfide bonds in the gel matrix (Table 3). Zhao et al. [50] applied ultrasound-treated carrageenan to a low-salt chicken meat paste. They also reported that carrageenan improved the solubility of myofibrillar proteins through the interaction between carrageenan and protein, and the water-holding capacity through the interaction between carrageenan and water molecules. The application of ultrasound with plant polysaccharides in low-salt meat products not only improves the solubility of myofibrillar proteins but also improves microbiological safety, which can be a problem in low-salt meat products [50, 51]. Gao et al. [51] found that the combination of guar gum and ultrasound treatment in low-salt chicken myofibrillar protein emulsions synergistically improved emulsion stability by increasing emulsion viscosity and reducing droplet size.

The use of non-meat proteins in meat products improves their quality because of their emulsion and gel-forming capacities. Li et al. [52] observed a decrease in cooking loss and an increase in the hardness of low-salt pork myofibrillar protein gels when soy protein isolate was added with high hydrostatic pressure treatment. The use of chicken bone powder, a byproduct, to improve low-salt pork batter was investigated by Zhan et al. [53]. They found that the Ca^{2+} ions released from chicken bone transformed the conformation of myofibrillar proteins and consequently increased the hardness and chewiness with a decrease in the cooking loss of pork gel. However, the fat in the pork gel was not effectively holed by chicken bone powder [53]

Quality deterioration of low-salt meat products is primarily caused by the low solubility of myofibrillar proteins. The solubility of myofibrillar proteins in raw meat is an important processing property. Defective meat, such as PSE, has lower solubility of myofibrillar proteins, and consequently, its use results in quality deterioration of meat products [54, 55]. Therefore, the selection of raw meat with high myofibrillar protein solubility is extremely important to manufacture low-salt meat products. Various techniques have been developed to predict meat quality [56,57]. The selection of raw meat with proven quality using prediction techniques can effectively improve the quality of low-salt meat products.

Animal fat

Animal fat is a common ingredient in emulsion-type meat products. The addition of animal fat improves the processing yield, textural properties, and flavor of meat products, and 20–30% fat cooperates with emulsion-type meat products. However, excessive intake of animal fat containing saturated fatty acids in the human diet can cause various diseases, such as obesity, cardiovascular diseases, and cerebrovascular diseases [58]. Therefore, along with increasing interest in low-fat meat products, researches have focused on the maintaining of the overall quality while reducing fat content [11-13].

Reducing fat in meat products induces quality deterioration in terms of texture and flavor. Therefore, substances that compensate for the low quality of low-fat meat products are required. Plant polysaccharides are promising substitutes for fats. Bohrer et al. [59] found that a reduction in fat from 20% to 5% in beef batter resulted in decreased hardness and chewiness (Table 4). They applied microcrystalline cellulose as a fat substitute in beef batter containing 5% fat and observed the improvement of textural properties compared to those of beef batter with 20% fat [59]. Pietrasic and Soladove [60] used pea starch to improve the quality of low-fat bologna and reported that cooking loss decreased and hardness and chewiness increased. Sodium alginate was investigated as a fat replacement in frankfurters, in which the fat content was reduced from 18% to 3% with the addition of a sodium alginate solution [61]. Kang et al. [61] reported that sodium alginate in reduced-fat frankfurters led to the unfolding of the myofibrillar protein, transit of the-helix into other secondary structural forms, and formation of a network with a myosin tail, and found an increase in the cooking yield and hardness of reduced-fat frankfurters.

Vegetable oils are considered healthier lipids than animal fat because they contain more unsaturated fatty acids than animal fat. However, the addition of vegetable oils to meat products results in quality deterioration because the added oils are not effectively retained in the gel structures of the meat products. Recently, the use of structured or solidified oils, such as protein- or polysaccharide-based emulsions and Pickering emulsions, as alternatives to animal fat has increased [62, 63]. Zhao et al. [62] found that frankfurters containing a 7% pork back fat and 7% quinoa protein emulsion (protein:soybean oil, 3:1) had textural properties similar to those of frankfurters containing 14% pork back fat. In addition, the sensory properties of reduced fat (pork back fat) frankfurters do not differ from those of high-fat frankfurters [62]. Rezaee and Aider [63] used a Pickering emulsion manufactured using canola oil, canola protein, and xanthan as replacements for animal fat. The replacement of beef fat at 50% by a Pickering emulsion in the gel of mechanically separated meat showed no differences in cooking yield, firmness, or elasticity of the gel [63]. In addition, lipid oxidation in gels containing Pickering emulsions was inhibited during storage compared with gels containing animal fat [63].

Reinforcement of nutritional value

In previous sections, we discussed strategies to reduce or replace synthetic additive and ingredients in meat products that could potentially harm human health. There are also direct methods for enhancing the nutritional value of meat products by adding natural ingredients that exhibit health benefits.

Dietary fiber, as a substitute for synthetic additives or saturated fats, can also be integrated into meat products to promote better health. Incorporating dietary fiber into meat products has the potential to lower the calorie content per serving, aiding in weight management [64]. Notably, dietary fiber plays a positive role in human gut health. As dietary fiber remains undigested by human enzymes in the small intestine, it passes through the digestive tract intact, reaching the colon and supporting the growth of beneficial gut microbiota. Moreover, sufficient fiber intake can add bulk to the stool, aiding in maintaining regular bowel movements and preventing constipation [65]. Furthermore, research has indicated that dietary fiber may contribute to preventing chronic diseases by reducing serum lipid levels and blood pressure as well as regulating blood glucose concentrations to manage diabetes [66]. Among the various types of dietary fiber that are incorporated into meat products, carrageenan is often used for its stability under cold and freeze–thaw conditions and water-binding properties, and oat, soy, pea, psyllium, cellulose, and vegetable fibers are suitable choices for enhancing meat products [64, 67]. Dietary fibers such as pectin, glucans, cellulose derivatives, inulin, chitosan, and gums have emerged as natural emulsifiers, effectively stabilizing lipid droplets through their surface-active properties at the oil–water interface and enhancing viscosity in the continuous phase [66]. Incorporating these natural emulsifiers not only bolsters the stability of meat products but also presents potential health benefits through improved emulsion properties. However, further investigations are required to explore the direct effects of dietary fiber addition to meat products on human health.

Interestingly, the primary nutrients in meat that can potentially cause adverse health effects are protein and fat. This susceptibility arises from the excessive oxidation of fats and proteins during processing, storage, and cooking, resulting in the formation of carcinogens [68,69]. Consequently, studies have been conducted to mitigate oxidation and reduce potentially carcinogenic compounds by altering the raw meat characteristics or incorporating natural antioxidants. The presence of saturated fatty acids and cholesterol in meat products has raised concerns among consumers regarding health issues and cardiovascular diseases [58]. As a result, verifying the fatty acid profiles of meat has garnered attention. A study conducted an examination of the fatty acid composition of grain- and grass-fed beef rich in saturated fatty acids reported that grass-fed beef exhibited a reduction of 2,773 mg in total saturated fatty acids compared with grain-fed beef [70]. Additionally, grass-fed beef has an elevated content of n-3 polyunsaturated fatty acids, which offer enhanced health benefits. The authors noted that grass-fed beef provided heightened protection against cardiovascular diseases. Furthermore, Zhang et al. [71] explored the influence of probiotics in feed and revealed the augmented presence of arachidonic acid, eicosapentaenoic acid, and gamma-linolenic acid in sheep meat, leading to an improved fatty acid composition. The increased content of unsaturated fatty acids contributes to a reduction in low-density-lipoprotein cholesterol, commonly referred to as 'bad' cholesterol, while concurrently elevating high-density lipoprotein cholesterol. High-density lipoprotein cholesterol facilitates the removal of excess cholesterol from the bloodstream, thereby reducing the risk of cardiovascular disease [72]. Moreover, n-3 fatty acids are recognized for their anti-inflammatory properties and potential to enhance brain function [71]. Consequently, a higher n-3 fatty acid content has the potential to increase the nutritional value of meat products.

Although increasing the presence of unsaturated fatty acids in meat products imparts health advantages, it also introduces potential concerns related to lipid oxidation. Lipid oxidation is primarily driven by processes such as free-radical chain reactions, metal ion-catalyzed oxidation, and photooxidation, ultimately yielding oxidative byproducts that can have adverse health implications, such as mutagenic and genotoxic effects [73]. Given the inherent antioxidant properties of plant extracts, the incorporation of natural antioxidants has been shown to prevent oxidative progress in meat products [74,75]. In a study by Kim et al. [76], the introduction of loquat leaf extract into restructured beef jerky effectively inhibited lipid and protein oxidation during storage through the radical scavenging and chelating capacities of the extract. Lee et al. [77] compared 25 natural extracts and highlighted the potency of *Nelumbo Nucifera Gaertner* extract in reducing lipid oxidation in pork sausages during storage. However, a different perspective emerged from the studies by Bae et al. [74] and Yoon et al. [75], where the use of plant extracts as natural curing agents paradoxically led to an increase in lipid oxidation during storage due to a reduction in residual nitrite content due to the incorporation of antioxidants. Hence, there is a crucial need to comprehensively understand the effects and underlying mechanisms of action of plant extracts in processed meat products, specifically their effects on oxidation.

Antioxidants play a significant role in inhibiting the generation of potential carcinogens in meat products. As part of the processing, meat products often undergo curing and smoking. However, when these products are cooked at high temperatures, the formation of carcinogenic compounds such as polycyclic aromatic hydrocarbons (PAHs), N-nitroso compounds, and nitrosamines can be triggered [78]. PAHs are hydrocarbon molecules characterized by multiple benzene rings. Although lighter PAHs with two or three rings (such as naphthalene, fluorine, and acenaphthene) are less toxic owing to their volatility, more stable and heavy PAHs (such as pyrene, chrysene, and fluoranthene) tend to exhibit greater toxicity [68]. In addition, nitrosamines often arise in meat products through reactions between nitric oxide or nitrite and nitrozable substrates such as secondary amines [69]. The primary mechanism of inhibiting the generation of PAHs and N-nitroso compounds is the ability of antioxidants to scavenge free radicals [68,79]. Cho et al. [80] demonstrated that the addition of a 0.4% *Perilla frutescens* extract to pork patties hindered both lipid oxidation and PAH formation. Similarly, Shen et al. [81] found that adding 2.5% green tea extract to roasted ducks substantially suppressed PAH formation by 79.7%, owing to its abundant phenol content. Deng et al. [82] reported that the inclusion of apple polyphenols (0.03%) in dry-fried bacon reduced N-nitrosomethyl phenylamine formation and mitigated lipid and protein oxidation. By incorporating natural antioxidants, the production of harmful oxidative byproducts and reactive species can be minimized, and the consumption of these antioxidants can also yield additional health benefits for individuals by reducing oxidative stress and promoting the overall well-being.

As meat is a protein-rich food, assessing its nutritional value often involves evaluating protein quality through amino acid composition and protein bioavailability. Although meat exhibits excellent protein digestibility in the human body, digestibility can be altered during processing or storage. This is particularly important for specific groups such as infants, older adults, and patients, where low digestibility might be a challenge, necessitating efforts to enhance protein digestibility in meat and meat products to optimize post-intake utilization and digestion efficiency [83]. Enhanced protein digestibility in meat is frequently achieved through both thermal and nonthermal treatments. High-temperature cooking (≥100 ℃) during processing can lead to reduced digestibility, owing to muscle fiber shrinkage and protein coagulation. In contrast, mild cooking temperatures (60–80 ℃) promote digestibility by facilitating protein unfolding [84]. As a result, studies exploring methods such as sous-vide cooking [85,86], application of pressure during heating to induce meat protein dissociation [87], and optimization of conventional cooking techniques (stewing, grilling, roasting, frying, etc.) have been undertaken [88-90]. Nonthermal treatments may involve conventional aging and nonthermal technologies [91]. Conventional aging enhances the in vitro protein digestibility of beef [92], and a recent study by Lee et al. [93,94] revealed that pre-freezing prior to aging can further accelerate beef protein degradation, leading to even greater in vitro protein digestibility. Non-thermal technologies induce changes in native intra-/intermolecular interactions, altering secondary, tertiary, and quaternary structures, thereby affecting the digestive properties of meat [83]. Non-thermal methods such as high-pressure processing [91], pulsed electric field [95], and ultrasound [96] have also been reported to enhance protein digestibility in meat. However, it is important to approach non-thermal techniques with caution, as alterations in protein oxidation and denaturation can be substantial, even in the absence of heat-induced changes, necessitating careful investigation of the appropriate conditions [83].

In addition, the enhancement of the attributes of meat products can involve the modification of lipid digestibility. A notable challenge in reducing animal fat content is the potential deterioration of sensory qualities. Given that fats considerably contribute to the sensory appeal of meat products, a novel approach has been proposed to reduce the digestion and absorption rates of fats without directly decreasing their content [66]. In this approach, lipid encapsulation is widely used, involving the direct emulsification of lipid sources with stabilizing agents such as biopolymers and low-molecular-weight surfactants [97,98]. The reduction in lipid digestibility and digestion rates using post-encapsulation is mainly attributed to hindered diffusion and limited access of lipases to lipid droplets [66]. Santiaguín-Padilla et al. [99] examined the encapsulation of pork fat in meat emulsions with pectin and observed a 20% reduction in triglyceride degradation during in vitro digestion. Similarly, Cofrades et al. [100] employed 1% methylcellulose in pork lard emulsions and reported an 18% decrease in the extent of lipolysis after encapsulation. Diao et al. [101] used glycerolysis of triacylglycerol in pork lard to transform it into diacylglycerol with lower fat accumulation in the human body. The lipid digestibility of lard emulsion enriched with diacylglycerol surpassed that of conventional pork lard; however, the researchers observed that a higher diacylglycerol content could potentially reduce fat accumulation in the body after absorption [101]. Although many studies have focused on the encapsulation of lipid sources with functional ingredients in food emulsions [63, 98, 102], the application of encapsulated fats in meat products and the resulting changes in lipid digestibility should be further investigated in the future studies.

Summary

Meat products can supply high-quality protein to humans and are very important in the meat industry in terms of promoting the added value of fresh meat. Improvement in the quality of meat products is required in various aspects to meet consumer needs.

After reviewing recent literature, we identified three strategies for improving meat product quality: replacement of synthetic additives, reduction of unhealthy ingredients, and reinforcement of the nutritional value of meat products. We observed that the substances containing dietary fiber used in all three strategies had various functions. To replace synthetic additives, natural plant powders can be converted into natural nitrite sources by cold plasma treatment. Natural plant powders have been shown to replace phosphate in meat products because of their water- and fat-binding abilities. Plant polysaccharides improve the quality of low-salt meat products by improving the water-holding capacity and emulsion stability through interactions between polysaccharides and water, protein, or fat. Emulsions of vegetable oils, proteins, and polysaccharides have shown a good ability to substitute animal fat in meat products. In addition, dietary fiber has various biological functions that prevent various diseases in the human body. Therefore, the addition of dietary fiber substances to meat products improves their quality by replacing nitrite and phosphate, reducing salt and fat, and reinforcing nutritional values. However, the use of dietary fiber sources in meat products has mostly been conducted for one objective such as synthetic additive replacement or the reduction of unhealthy ingredients.

In future studies, we believe that the effect of dietary fiber sources in meat products must be investigated for their multifunctional roles as both substitutes for synthetic additives and partial substitutes for salt and animal fat, as well as for nutritional value improvement. In addition, polysaccharides have different properties in terms of surface charge and activity of water, proteins, and fat molecules. Therefore, optimal sources and dosages for the quality of meat products must be determined. This is an appropriate method to improve the quality of meat products with minimal processing.

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Tables

Table 1. Recent studies for the replacement of synthetic nitrite in meat products.

Ingredients/technologies	Meat product type	Effects	Mechanism	Reference
Arugula extract (pre-converted from nitrate to nitrite)	Fermented sausage	Development of cured color Reduction of lipid oxidation	Nitrite converted from endogenous nitrate	Serdaroğlu et al. [1]
Celery powder (pre-converted from nitrate to nitrite)	Pork emulsion sausage	Improvement of color Undesirable texture properties	Nitrite converted from endogenous nitrate	Jin and Kim [22]
Radish derivatives (pre-converted from nitrate to nitrite)	Restructured cooked ham	Development of cured color No undesirable flavor	Nitrite converted from endogenous nitrate	Guimaraes et al. [23]
Milk powder (cold plasma treated)	Pork sausage	Development of cured color Inhibition of lipid oxidation Inhibition of total aerobic bacteria growth Desirable texture property	Generation of nitrite in milk by cold plasma treatment, Addition of more protein	Marcinkowska-Lesiak et al. [29]
Winter mushroom powder (cold plasma treated)	Ground ham	Development of cured color Inhibition of lipid oxidation	Generation of nitrite in winter mushroom homogenate by cold plasma treatment	Jo et al. [17]
L-arginine and Lactobacillus fermentum	Pork meat batter	Generation of nitrosyl-myoglobin, increase in red color	Production of nitric oxide	Luo et al. [30]
Ultrasound treatment	Pork meat batter	Generation of nitrosyl-myoglobin, increase in red color	Production of nitric oxide from L-arginine in pork meat using ultrasound treatment	Leães et al. [32]

Table 2. Recent studies for the replacement of inorganic phosphate in meat products.

Ingredients/technologies	Meat product type	Effects	Mechanisms	Reference
Seaweed dietary fiber	Frankfurter	· Decrease in cooking loss · Increase in emulsion stability · Improvement in textural properties · Inhibition of lipid oxidation	Improvement of water holding capacity Increase of antioxidant activity	Yuan et al. [38]
Winter mushroom powder	Beef patty	· Decrease in cooking loss · Inhibition of lipid oxidation · Reduced hardness	Increase of pH Improvement of water holding capacity Increase of antioxidant activity	Jeong et al. [6]
Hot-boned pork with winter mushroom powder	Pork gel	· Decrease in cooking loss · Reduced hardness	Increase of pH Improvement of water holding capacity Increase of antioxidant activity Low actomyosin content	Jeong et al. [2]
Bamboo fiber and ultrasound treatment	Meat emulsion	· Increase in emulsion stability · Improvement in textural properties	Increase of pH Improvement of water holding capacity Modification of protein structure	Pinton et al. [40]
Soy protein isolate hydrolysates with high pressure processing	Pork emulsion	· Increase in emulsion activity and stability · Inhibition of lipid oxidation · Decrease in droplet size	Improved interaction between lipids and proteins Increase of antioxidant activity	Guan et al. [42]
High pressure processing	Pork gel	· Increase in myofibrillar protein solubility · Low gel strength	Actomyosin dissociation	Jeong et al. [43]

Table 3. Recent studies for the reduction of sodium chloride.

Ingredients/technologies	Meat product type	Effects	Mechanisms	Reference
Konjac glucomannan	Beef myofibrillar protein gel (0.3 M NaCl)	· Increase in the gel strength	Unfolding of myofibrillar proteins Promotion of disulfide bonds in the gel matrix	Gao et al. [49]
Carrageenan with ultrasound	Chicken meat paste (1.0% NaCl)	· Decrease of cooking loss · Improvement of texture properties	Increase in myofibrillar protein solubility via ultrasound treatment and interaction between carrageenan and proteins Improvement in water holding capacity by the hydrogen bond between carrageenan and water molecule	Zhao et al. [50]
Guar gum with ultrasound	Chicken myofibrillar protein emulsion (1.0% NaCl)	· Improvement of emulsion stability	Increase in emulsion viscosity Reduction of droplet size	Gao et al. [51]
Soy protein isolate with high pressure processing	Pork myofibrillar protein gel (1.0% NaCl)	· Decrease of cooking loss · Improvement of texture properties	Improvement of water and fat holding capacity	Li et al. [52]
Micro-/nano-scaled chicken bone	Pork batter (0.5% NaCl)	· Decrease of cooking loss · Increase of hardness and chewiness	Promotion of protein orderly aggregation by conformational transition of protein	Zhang et al. [53]

Table 4. Recent studies for the reduction of animal fat.

Ingredients/technologies	Meat product type	Effects	Mechanisms	Reference
Microcrystalline cellulose	Beef batter (5% fat)	Improvement in texture properties	Increase in water holding and gel rigidity	Bohrer et al. [59]
Pea starch	Bologna (18% fat)	· Improvement in cooking yield Improvement in hardness and chewiness	Increase in water holding capacity Gel forming ability	Pietrasik and Soladoye [60]
Sodium alginate	Frankfurter (10% fat)	· Improvement in cooking yield · Improvement in hardness	Increase in water holding capacity Interaction between myosin tail and alginate	Kang et al. [61]
Quinoa protein emulsion (protein : soybean oil, 3 : 1, v/v)	Frankfurter (50% fat replacement)	· No differences in cooking yield, texture properties, and sensorial properties	Increase in water holding capacity Interaction between quinoa protein and water molecules Conformation of uniform and compact gel structure	Zhao et al. [62]
Canola proteins-xanthan based Pickering emulsion	Mechanically separated meat gel (50% fat replacement)	· No differences in cooking yield and textural properties (firmness and elasticity) · Increase in unsaturated fatty acid composition · Decrease in lipid oxidation	Specific mechanisms were not reported	Rezaee and Aider [63]