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Controlling Ingredients for Healthier Meat Products: Clean Label

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Abstract: Many ingredients are incorporated in the manufacture of meat products. Some of them are necessary to improve flavor, taste, and texture of meat products. However, excessive addition of processing ingredients such as fat, sodium, and other curing agents might cause health problems such as obesity, diabetes, and chronic diseases. Therefore, it is recommended that the minimum amount necessary of these ingredients be incorporated in the manufacture of meat products. This review summarizes minimum levels of key ingredients for the manufacture of meat products with maximum palatability. Functional ingredients that should be added in the process of meat products are also discussed. Thus, the reduction of undesirable ingredients and the addition of functional ingredients could be achieved to develop healthier meat products for consumers.

Key words: processing ingredients, meat products, curing agent, healthier meat products
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Introduction

Although meat and meat products are good sources of nutrients such as protein, fat, vitamins, and minerals, they might have negative effects on human health if these ingredients change to unknown toxic materials during processing, storage, and marketing processes. Such toxic materials can harm human health (Jiménez-Colmenero et al., 2001). Among curing agents, salt (NaCl) is a key ingredient that can function in taste, flavor, and texture of meat products. It also extends shelf-life during the storage of meat and meat products (Terrell, 1983). However, excess intake of salt may cause metabolic diseases (such as high blood pressure) and cardiovascular disease. Therefore, reducing salt intake is strongly recommended to reduce the risk of those diseases (Dietary Guideline for Americans, 2010). Sodium nitrite ($NaNO_2$) serves as the most important curing agent affecting color and taste of meat products, and it extends the shelf-life of meat products by inhibiting microorganisms, especially *Clostridium botulinum*, along with salt. However, nitrosamine, a carcinogen, might be produced during the higher-temperature cooking of meat products such as bacon (Hotchkiss and Cassens, 1987). Therefore, the addition levels of sodium nitrite should be reduced as much as possible to prevent the formation of carcinogenic compounds. Sodium tripolyphosphate is also added to maintain water-holding capacity during cooking and storage, resulting in improved textural properties (Terrell, 1983). Since there was a correlation between phosphorus levels and cardiovascular disease, excess intake of phosphate also should be avoided (Dhingra et al., 2007).

Functional ingredients extracted from fruits and vegetables can function as antioxidants, antimicrobial agents, and immune-enhancing materials (Jiménez-Colmenero et al., 2001). The drying process of various vegetables and fruits has been used to activate the maximum extraction of functional ingredients. For example, dried tomato (Kim and Chin, 2016), persimmon by-products (Ramachandraiah et al., 2017; Ramachandraiah and Chin, 2017a, 2017b), *Cudrania tricuspidata* leaves (Cuong and Chin, 2018), onion, and garlic (Park et al., 2008) can function as natural antioxidants and antimicrobial agents to extend shelf-life of meat products. Healthier meat and meat products should reduce their addition of undesirable ingredients and processes by increasing the amount of beneficial substances through reformulation. To produce healthier meat and meat products, ingredients that might be toxic for humans should be properly avoided or have their amounts reduced, whereas beneficial bioactive substances should be added. Therefore, reformulated meat products have been suggested to reduce fat and sodium contents and other curing agents while increasing levels of functional ingredients. The objective of this paper was to review ingredients that are widely used in meat products and to suggest ways to control these ingredients through optimal combination for the manufacture of healthier meat products.

Fat

The need for low-fat meat products

Fat provides 2.25 times more calories than protein and carbohydrates. It is an essential nutrient that can provide essential fatty acids, such as linoleic acid, linolenic acid, and arachidonic acid, which are not synthesized in our body, and is needed to facilitate the absorption of fat-soluble vitamins (A, D, E, K) (Dietary Guideline for Americans, 2010). It contributes to desirable sensory traits—such as flavor, texture, and taste—that are highly correlated with palatability (Tobin et al., 2013). Although consumers prefer taste and sensory characteristics of regular-fat meat products (RFMPs; ~30%), they might purchase low-fat foods for the health benefit. Normally, fat content in commercial cooked meat products may be as high as 30% (Keeton, 1994), ranging from 15% to 30% in comminuted sausages in Korea. Other meat products also contained at least 10% fat content (Chin et al., 2006).

Although fat is a necessary nutrient to maintain human health and an important ingredient for sensory characteristics of processed meats, it increases the risk of chronic diseases, such as cardiovascular disease, diabetes, and certain types of cancer if excessive fat is taken (Dietary Guideline for Americans, 2010). The American Heart Association has recommended that the daily dietary allowance of fat, saturated fat, and cholesterol be limited to no more than 30%, 10%, and 300 mg, respectively (Krauss et al., 2000). Furthermore, excessive fat in diet is highly related to obesity and other metabolic diseases (Jiménez-Colmenero, 1996; Desmond, 2006). Coronary heart disease and obesity are caused by the excessive storage of calories due to a high-fat diet. World Cancer Research Fund International has reported that overweight and obesity could lead to some types of cancer (WCRF, 2007). Many studies have been performed to reduce fat content or introduce fat replacements for the development of low-fat meat products (LFMPs). Thus, an understanding of the functions of fat associated with texture and flavor is needed to replace fat in muscle foods (Tobin et al., 2013, McClements and Decker, 2008).

Flavor

LFMPs are generally produced by imitating sensory characteristics of RFMPs (Keeton, 1994). However, LFMPs might have problems related to reduced aroma from animal fat, resulting in less palatability for the consumer compared to RFMPs. Many studies have been conducted to develop fortified flavor ingredients of LFMPs. Yoo et al. (2005) reported that flavor profiles of low-fat sausages (LFSs) are different from those of regular-fat sausages (RFSs). Volatile compounds, such as 4-acethyl-3-methyl pyrazole, 1,4-dimethyl benzene, p-ethylguaiacol, and beta-caryophyllene, were contained in RFSs. However, amounts of myristine and hexadecanoic acid were higher in LFSs than in RFSs. Park et al. (2009) suggested that the the addition of carbohydrates such as glucose, fructose, and sucrose at a concentration higher than 0.05 M in combination with 0.1 M lysine can delay the release of some flavor compounds in LFMPs. The use of oils from plants, fish, and microalgae has been extensively studied to improve the amount of volatile compounds in sausages for increased levels of fatty acids. Moreover, these oils in meat products provide omega-3 and omega-6 fatty acid. Fish oil has been used as a substitute for 30% pork back-fat in fermented sausages because it can contribute to sensory attributes (Josquin et al., 2012). Soy protein mixtures with rapeseed oil or high oleic sunflower oil can replace 12% fat in sausages without adversely affecting sensory attributes or shelf-life (Asuming-Bediako et al., 2014). Alejandre et al. (2016) have reported that the use of linseed oil gel emulsion as a fat replacer can increase the number of volatile compounds such as hexanal, heptanal, and nonanal in dry fermented sausages. Approximately 32% replacement of animal fat could be acceptable for consumption without detrimental effects on color, taste, or juiciness. Because oil-enriched fat replacers contain many unsaturated fatty acids, lipid oxidation produced by these oils might occur during storage, which could be a limitation of adding unsaturated oil to commercial meat products. However, the meat ripening process can slightly prevent lipid oxidation of these oils. Delgado-Pando et al. (2011) prepared healthier lipid combinations of vegetable oil with a different protein system such as sodium caseinate (SC) or soy protein isolate (SPI) and reported that, despite slightly increasing lipid oxidation during storage, these combinations contributed to nutritional advantaged, and improved sensory attributes and technological properties.

Texture

To compensate for the textural defects of LFMPs, many studies have been performed using nonmeat proteins, hydrocolloids, and other biomolecules. The fat replacers such as konjac flours, carrageenan, and starch alone or in combination have been extensively studied and have successfully replaced fat in LFMPs similar to those in RFMPs (Chin, 2000; Chin et al., 1998a, 1998b, 1999, 2000, 2009a). They reduced the expressible moisture (percentage) and textural defects of LFMPs. In addition, these fat replacers and sodium lactate increased shelf-life by retarding growth of *Listeria monocytogenes* during refrigerated storage (Choi et al., 2003). Felisbeto et al. (2015) reported that prebiotic fibers (inulin, polydextrose, and resistant starch) and starch substitutes improved tenderness and increased gelation temperatures. Han and Betram (2017) studied the effect of the addition of various dietary fibers (inulin, dextrose, carboxyl cellulose, chitosan, pectin) on water distribution, water-binding capacity, and textural properties of a reduced-fat model meat system. They reported that dietary fiber enrichment reduced cooking loss and improved water-binding capacity, whereas its effect on texture was varied, depending on the specific dietary fibers, which were optimized to promote specific and desired technological attributes for healthier meat products. Varga-Visi and Toxanbayerva (2017) suggested that replacement of fat with gelling agents leads lead to be firmer, dry, and rubbery products, whereas substitution of fat with water at the ratio of 1:1 resulted in an unacceptable soft texture. Therefore, formulations should be balanced the ratio of moisture and fat, resulting in similarity to the regular-fat (30%) control.

Salt

The need for low-salt meat products

Salt is added to several foods, especially in the manufacture of meat products, for many functions. The term “sausage” is from the Latin words “*salsus*,” meaning “salt” or chopped/minced meat preserved by salting (Pearson and Gillett, 1999). It not only leads to a salty taste but also can extract salt-soluble protein (SSP) and interact with water, fat, and protein binding, resulting in desirable texture (Marsh, 1983). Because the addition of salt can improve water-holding capacity with increased solubility of protein, it can reduce water loss during processing and storage (Terrell, 1983), and importantly, the addition of salt maintained microbial stability and safety of foods during storage (Brewer et al., 1995).

Types of sodium in meat products include sodium chloride, sodium phosphate, monosodium glutamate, and sodium lactate. Among various sodium additives, sodium chloride has the highest amount of sodium. Cooked meat products contain sodium chloride at levels ranging from 1.5% to 3.0%. Sodium chloride is added to meat products to extract SSP, resulting in improved water- and fat-binding ability of meat products. Moreover, sodium chloride has been used to enhance the flavor of meat products and (due to decreased water activity) extend their shelf-life, not only of pasteurized meat products, but also of long-term–ripened meat products.

Since high sodium intake has been considered a major cause of hypertension during the last few decades, the use of salt in animal-derived food products has been regarded as a negative influence on human health (Pearson and Wolzak, 1982). High sodium intake has been related to the incidence of high blood pressure, cardiovascular disease, and stomach cancer (Aburto et al., 2013). Thus, the development of healthier foods with reduced salt levels is required to meet consumer demand (Resurreccion, 2003). Delgado-Pando et al. (2018) determined the minimum acceptable level of salt in whole-muscle cured meat products (bacon and ham) and reported that reduced-salt products had increased hardness and higher microbial counts. They demonstrated that it was feasible to reduce levels by 34% in bacon and 19% in ham, respectively, but that further salt reduction might compromise product quality and safety.

Although meat producers could manufacture meat products with reduced salt, sensory characteristics might be worsened when fat and salt contents are decreased. Since levels of added salt can significantly affect the yield, taste, and flavor of final products, the sensory preferences of consumers could be decreased (Ruusunen et al., 1999, 2003; Ruusunen and Puolanne, 2005). A salt mixture could decrease the perceived saltiness of LFMPs. Researchers are continuing to manufacture a salt replacer that could be added to the meat products directly. Ruusunen and Puolanne (2005) suggested several approaches for salt reduction: (1) reduced salt, (2) salt alternatives, (3) substituting all or part of NaCl with other sodium salts, (4) replacing part of the NaCl with nonchloride salt, such as phosphate, and (5) replacing part of the NaCl with new processing techniques and process modifications (Terrell, 1983). Shazer III et al. (2018) reported that the replacement of traditional brewed soy sauce (SS) and fermented flavor enhancer (NFE) improved sensory saltiness without negative effect. They concluded that flake salt replaced with either SS or NFE for bacon (50% and 75% SS or NFE), beef jerky (50% and 75% SS or NFE), and summer sausage (50% SS and 50% NFE) increased saltiness without product defects. The other technology for the replacement of salt in processed meats could use a halophyte such as glasswort. Kim et al. (2014) reported that the addition of glasswort in low-salt sausages could successfully reduce the salt level by about 50% without defects. A combination of sea mustard and phosphate could reduce one-third of the original salt levels in a low-fat meat emulsion (Kim et al., 2015).

Many factors affecting the perception of salt, which might be optimized by the physical form of the salt, resulted in a reduction of salt in meat products (Desmond, 2006). For example, salt particle size and shape are factors affecting the perception of salt in solid forms. Small particles of salt dissolve faster than larger particles in foods. When the physical form of salt changes from granular to flake, it provides good absorption and more rapid solubility in food (Campell, 1979). As high-solubility proteins could expose the surface area, the small particle size and flaked shape of salt have been shown to have highly functional properties in LFMPs. Thus, changing the physical form of salt can lead to more taste than that is bioavailable and reduced amounts of added salt (Desmond, 2006).

Technology for substitution of salt in meat products

Sodium replacers. Because salt plays a key role in meat products, there are many advantages if salt is incorporated with other ingredients (such as phosphate) into the meat product. Water-holding capacity is decreased when salt levels are decreased in meat products, but by adding phosphate, both water-holding capacity and sensory properties might be improved while reducing the sodium content.

Ruusunen et al. (2001a) studied the effects of 6 different levels of fat and 2 different levels of salt on perceived saltiness of cooked bologna-type sausage. They found that replacing lean pork with pork fat could increase the perceived saltiness of sausages and that monosodium glutamate could increase sensory properties of cooked sausages. Ruusunen et al. (2001b) reported that cooked hams with salt levels of 1.1% had different cooking loss compared to those with salt levels of 1.4% or higher. Sodium could be reduced by up to 50% without causing differences in physical properties by adding phosphate (Jiménez-Colmenero et al., 2001). Choi and Chin (2020) reported that, when chicken model sausages with various salt contents (0.5%~2.5%) were manufactured, expressible moisture (%) and cooking loss (%) results were decreased with increasing salt concentration ($P < 0.05$) (Table 1). Among salt levels from approximately 0.5% to 2.5%, salt levels of 1.5%, 2.0%, and 2.5% showed lower expressible moisture values than those of salt levels (>1.0%), with 2.5% salt being the best ($P < 0.05$). Cooking loss also differed with a 1.0% or higher salt level compared to a 0.3% salt level (Table 1). In addition, textural hardness values of sausages with salt levels of 1.0% were higher than those of sausages with salt levels of 0.5%. These results showed that the reduced salt level might have products defects. Thus, it could be used as a supplement to compensate for the defects of low-sodium meat products. In a model sausage, salt level could also be reduced. As shown in Table 2, approximately 0.3% phosphate could reduce salt level to about 1% in water holding capacity (Choi and Chin, 2020).

Table 1. Water-holding capacity of chicken model sausages as affected by different salt levels

		Salt Level				
Water-Holding Capacity		0.5%	1.0%	1.5%	2.0%	2.5%
Expressible moisture (%)	**Mean**	30.6^{a}	23.1^{b}	21.8^{b,c}	20.9^{b,c}	20.3^{c}
	SD	1.64	0.80	1.67	1.88	0.37
Cooking loss (%)	**Mean**	3.00^{a}	1.13^{b}	0.54^{b,c}	0.33^{c}	0.27^{c}
	SD	0.61	0.48	0.16	0.08	0.01

^{a,b,c}Means with the same superscript are not different (Choi and Chin, 2020).

Table 2. Water-holding capacity of chicken model sausages as affected by different salt and phosphate combinations

		Salt (S) and Phosphate (P) Combinations (%)					
Water-Holding Capacity		S0P0	S0P0.3	S1P0	S1P0.3	S2P0	S2P0.3
Expressible moisture (%)	**Mean**	41.3^{a}	41.7^{a}	40.6^{a}	30.8^{b}	33.9^{b}	22.4^{c}
	SD	1.75	1.83	0.77	1.93	3.45	1.71
Cooking loss (%)	**Mean**	7.30^{a}	5.58^{b}	4.04^{c}	2.39^{d}	2.81^{d}	0.34^{e}
	SD	0.75	0.66	0.64	0.49	0.29	0.11

^{a,b,c,d,e}Means with the same superscript are not different ($P < 0.05$) (Choi and Chin, 2020).

There are many ions, such as potassium and calcium chloride, to replace salt in various meat products. Blesa et al. (2008) reported that the combination of sodium, potassium, calcium, and magnesium chloride in Spanish cured ham extended shelf-life to a range similar to hams with 100% sodium chloride. However, the lower-sodium hams need more time for post-salting than higher-sodium ham.

Microbial transglutaminase. Microbial transglutaminase (MTGase) is an enzyme used for crosslinking between glutamine and lysine in several foods, including muscle foods. Hence, the ε-(γ-glutamyl)lysine (ε-(g-Glu)Lys) complex is formed (Folk, 1980). It has a molecular weight of 38,000 Da and consists of 331 amino acids (Motoki and Seguro, 1998). It has a wide pH range of 4 to 9 for its activity, and optimum temperature for its acidity was 50°C (Jaros et al., 2006). There are many studies on ε-(γ-glutamyl)lysine crosslinking distribution in several foods (Sakamoto et al., 1995), especially cured horse mackerel meat induced by drying (Kumazawa et al., 1993). MTGase has been extracted from several microorganisms, such as *Streptoverticillium mobarense*, *S. ladakanum*, *Bacillus subtilis*, and *Physarum polycephalum* (Ando et al., 1989). MTGase from *Streptoverticillium* species bacteria in particular can form stronger crosslinked gels than MTGase from other species (Jiang et al., 2000). Since low-salt meat products have problems related to reduced protein solubility and water-holding capacity, many studies have been performed to improve textural properties of low-salt meat products and LFMPs with MTGase. Hwang et al. (2008) reported that both incubation time and temperature affected the crosslinking of the MTGase. The viscosity of pork myofibrillar protein gel was increased with increased time and temperature. Since MTGase is an enzyme, it needs to have a substrate for the interaction of crosslinking. Kuraishi et al. (1997) reported that the restructured meat products in combination with MTGase and SC showed acceptable binding and that SC appeared to be a superior substrate for crosslinking to meat protein compared with soy protein, whey protein, and gelatin. Chin et al. (2009b) reported that SC could partially replace with SPI and a cold-set myofibrillar protein containing SC was produced during incubating protein sols with MTGase for 4 h. Thus, SPI could be partially replaced with SC at no more than 33% without affecting gelling properties. To compensate for textural defects of low-salt meat products, many proteins and hydrocolloids have been used for crosslinking. To manufacture low-salt meat products similar to the regular-salt restructured pork ham, at least 1% salt would be required with the addition of dairy proteins (1%) combined with MTGase (Lee and Chin, 2011). Curdlan, a hydrocolloid produced by *Alcaligenes faecalis* var. *myogenes*, has been used in various foods; 1% curdlan and 1% salt can reduce hardness and gumminess to levels similar to those of regular-salt (1.5%) meat products (Lee and Chin, 2019a). Lee and Chin (2019b) reported that the addition of gelatin in myofibrillar gels increased cooking yield and viscosity in low-salt (<1.0%) meat products. Jang and Chin (2011a, 2011b) reported that red bean protein and SPI could be good candidates for MTGase because they increased cooking yield and gel strength. Ramírez et al. (2006) reported that low-salt restructured fish products from Mexican flounder with 2 levels of salt (1.0% and 2.0%) improved the textural properties and puncture test of gels using MTGase. In addition to MTGase, other ingredients have been used to improve flavor and texture of low-salt products. The combination of MTGase with potassium chloride and magnesium chloride has been used to reduce salt-restructured caiman steak with similar salty flavor and consumer preference. It showed a synergistic effect on making low-sodium products when salt replacers (KCl and $MgCl_2$) were added together (Canto et al., 2014). When restructured cured meats with MTGase were cooked, denaturation of protein molecules induced the exposure of reactive groups, which could improve cohesiveness. Thus, low-salt (1.0%) restructured products with 0.3% MTGase improved mechanical and functional properties (Téllez-Luis et al., 2002). When MTGase was incorporated into other dairy products, reduced-salt restructured ham showed enhanced textural property, cooking yield, and sensory attributes (Lee and Chin, 2011). The addition of MTGase in low-salt meat products can reduce water-holding capacity, resulting in increased cooking loss (Hong and Chin, 2010). Many studies have extensively reported that the addition of hydrocolloids and nonmeat proteins can reduce moisture loss during cooking. Konjac flour improves textural and water retention properties of MTGase-mediated, heat-induced porcine myofibrillar protein gel. In this study, MTGase improved the gel strength at 0.1 and 0.3 M NaCl and storage modulus (G') at all salt concentrations, compared to control without MTGase ("Control") (Chin et al., 2009a). Many studies have also suggested that various nonmeat proteins and MTGase combinations affected gel strength and cooking loss. Hong and Chin (2009) reported that the calcium carbonate system consisting of sodium alginate to calcium carbonate to glucono delta-lactone at a ratio of 1.0:0.3:1.0 was the best cold-set gelation at low-salt concentration of 0.1 M and reported that MTGase and SC led to acceptable cold-set gel with improved texture and cooking yield. Hong and Chin (2010) reported that a combination of MTGase with the sodium alginate system had advantages in cold-set gelation system compared with the SA system alone for improving myofibrillar protein gel functionality. There are many other proteins—especially fish sarcoplasmic protein (Hemung and Chin, 2013, 2014a, 2014b, 2015)—and nonmeat ingredients such as mungbean protein (Lee and Chin, 2013a, 2013b; Lee et al., 2014a). The addition of red bean protein isolate, mediated by MTGase in myofibrillar protein gels, can improve water-holding capacity because MTGase can promote interaction among proteins (Jang et al., 2015, 2016; Lee et al., 2017).

Hot boning. "Hot boning," the removal of meat from the skeleton before pre-rigor, is not a new concept; this processing technique was started in the 1940s. Many studies have been conducted on muscle biology regarding negative characteristics of prerigor muscles compared to postrigor ones. Prerigor beef is prone to "cold shortening" during rapid chilling, resulting in tougher muscle (Cross and Seideman, 1985). Since hot boning occurs before glycolysis is fully completed, prerigor meat still has a high pH with good ability for extracting myofibrillar protein and stabilizing fat as well as good water-holding ability for further processing (Claus and Sørheim, 2006). Although the salted blends of prerigor pork reduced the 50% salt levels of frankfurter-type sausages, they had no adverse effect on physicochemical and sensory properties since prerigor pork had high pH and high water-holding ability compared to postrigor pork meat (Puolanne and Terrell, 1983).

Choi et al. (1987a) studied the effect of prerigor muscle with various salt and phosphate levels on protein solubility, functionality, and storage characteristics of preblended pork for the manufacture of frankfurter and concluded that more myosin heavy chain and actin were extracted from hot boning compared to cold boning. The addition of phosphate could reduce salt levels from 3.0% to 1.5% if 0.5% phosphate is used. In addition, salt can increase pH and thiobarbituric acid values. However, phosphate had little effect on the microbial growth of preblends during refrigerated storage (Choi et al., 1987b). Laury and Sebranek (2007) reported that modified atmosphere package with both carbon monoxide and carbon dioxide package for prerigor and postrigor pork sausages extended the shelf-life by reducing aerobic and psychrotrophic microbial growth and improved oxidative stability and color compared to the oxygen-permeable film.

Prerigor meat processing was accomplished by Lee et al. (2014b), who reported that cold batter mincing of hot-bonded and crust-frozen air-chilled turkey breast allowed for reduced sodium content in meat protein gels. They concluded that hot boning and one-quarter of crust-frozen air chilling improved protein functionality, such as protein solubility and torsion test of turkey breast meat.

Since there is no limitation for salt level in the manufacture of meat products, salt level might be of interest to consumers. It is determined according to the type of a product. In South Korea, domestic meat products usually contain about 1.5% of salt but up to 3% of salt (Kim et al., 2004).

Kim and Chin (2019a) reported that prerigor ("Pre") ham with 1.0% salt was comparable to postrigor ("Post") ham with 1.5% salt. There was no difference in hardness, gumminess, chewiness, or cohesiveness between "Pre" (salt 0.5%~1.5%) and "Post" (salt 1.5%) sausages (Table 3). Springiness values of Pre-1.0% and Pre-1.5% salt were higher than those of Post-1.5%, while those of Pre-0.5% salt were not different from those of other treatments. In general, meat products with high salt content tended to have higher springiness. However, Pre-1.0% salt showed higher springiness than Post-1.5% salt. Pork sausages

Table 3. Texture profile analysis of pork sausages as affected by different rigor state and additional levels of sodium chloride (Kim and Chin, 2019a)

	Hardness (gf)	Springiness (mm)	Gumminess	Chewiness	Cohesiveness
Treatments[1]					
Post-1.5	5,330 ± 1,308^{NS}	5.50 ± 1.09^{b}	60.0 ± 26.2^{NS}	302 ± 81.7^{NS}	0.01 ± 0.00^{NS}
Pre-0.5	5,278 ± 898	5.93 ± 0.78^{a,b}	53.3 ± 15.4	309 ± 79.7	0.01 ± 0.00
Pre-1.0	6,171 ± 1,467	6.54 ± 0.77^{a}	61.5 ± 19.4	408 ± 149	0.01 ± 0.00
Pre-1.5	5,639 ± 751	6.61 ± 0.50^{a}	50.2 ± 9.37	326 ± 42.8	0.01 ± 0.00
Storage					
Fresh	6,197 ± 672^{a}	5.85 ± 0.96^{NS}	65.4 ± 12.9^{a}	375 ± 79.5^{NS}	0.01 ± 0.00^{NS}
Frozen	5,012 ± 1,199^{b}	6.43 ± 0.74	47.1 ± 18.1^{b}	298 ± 106	0.01 ± 0.00

[1] Post-1.5: pork sausage (PS) with 1.5% salt using postrigor muscle; Pre-0.5: PS with 0.5% salt using prerigor muscle; Pre-1.0: PS with 1.0% salt using prerigor muscle; Pre-1.5: PS with 1.5% salt using prerigor muscle.

NS = not significant among the column.

[a,b] Means having different superscripts in the same column are different ($P < 0.05$).

made with prerigor muscle containing 1.0% salt were similar to those of postrigor ones containing 1.5% salt, indicating that the salt level of sausages could be reduced by approximately one-third of regular-salt (1.5%) products. In addition, prerigor muscle in reduced-salt (<1.0%) pork sausages and prerigor muscle in regular-salt (1.5%) sausages made with postrigor muscle had similar quality characteristics.

Sodium Nitrite

The need for sodium nitrite replacement or reduction

The color of meat products may affect the purchasing decisions of consumers. An important ingredient for cured meat products such as ham and sausages, sodium nitrite (NaNO$_2$) has several functions. First, it can react with myoglobin during the processing of meat products and cooking to develop a cured pink color, nitrosohemochrome (Pearson and Gillett, 1999). Additionally, many studies have detailed the ability of sodium nitrite to inhibit the growth of various pathogenic microorganisms. Nitric oxide (NO) can prevent spoilage from several gram-positive bacteria. It can inhibit microorganisms by reacting with oxygen to form nitrogen dioxide and peroxynitrite ions (Klebanoff, 1993; Friedman et al., 2011). Al-Ahmad et al. (2008) reported that a low concentration of sodium nitrite (0.001%–0.02%) as a food preservative inhibited the growth of *Lactobacillus curvatus* and reduced its specific bacteriocin. Due to the antimicrobial activity of sodium nitrite, it has been widely used in the food industry as a preservative to extend the shelf-life of foods along with sodium benzoate and potassium sorbate (Stanojevic et al., 2009). Nitrite has also been reported to be beneficial for health by controlling blood pressure and inhibiting gastrointestinal pathogens (Archer, 2002). Accordingly, nitrite can extend the shelf-life of meat products by inhibiting the growth of microorganisms and toxin production from *C. botulinum*, which produces a toxin that causes food poisoning (Christiansen et al., 1973). Since *C. botulinum* causes food poisoning and food-borne botulism that can paralyze and weaken muscles with dysphonia, it been found in vacuum packaged sausages that were firstly found in Korea on 2004. Thus, sodium nitrite is an important ingredient of meat products that can improve food safety and shelf-life.

Igene et al. (1985) suggested that nitrite functioned as an antioxidant by forming a complex with heme pigments, thereby preventing the release of non-heme iron and subsequent catalysis of lipid oxidation. In a study by Osada et al. (2000), nitrite in meat products reduced the production of oxidative derivatives such as cholesterol. In addition, low concentrations of sodium nitrite (20 parts per million [ppm]) inhibited lipid oxidation in muscle of pork, chicken, and mackerel (Morrissey and Tichivangana, 1985).

Many previous studies have shown that sodium nitrite can improve the flavor of bacon (McDougall et al., 1975), ham (Kemp et al., 1975), and various comminuted meats (Wasserman and Talley, 1972; Waldman et al., 1974; Dethmers et al., 1975). Meat products containing sodium nitrite are heated and cooked to produce a unique flavor while inhibiting the occurrence of warmed-over flavor (Sato and Hegarty, 1971). Sodium nitrite also improved sensory characteristics by imparting a unique flavor to meat products (Noel et al., 1990). The mechanism of flavor development with sodium is inhibiting lipid oxidation caused by heme and nonheme iron as catalysts in meat products (Igene et al., 1985).

However, if sodium nitrite remains after color development, N-nitrosamine—a carcinogen—might be produced by interacting with sodium nitrite and amino acids or secondary amines in the digestive system of humans (Hawksworth and Hill, 1971; Anselme, 1979). Since processed meats are classified as Class 1 carcinogens by the International Agency for Research on Cancer as a part of the World Health Organization, consumers have a negative perception of processed meat products (Simon, 2015). Cassens (1995) suggested that foods most commonly contaminated with N-nitroso compounds can be classified into 6 broad groups: cured meats, some meat products and smoked fish, pickled and salt-preserved food, food stored under humid conditions and finally migration, and formation of nitrosamine from food contact materials. Kim and Chin (2019b) reported that the added nitrite was rapidly decreased during the first stage of storage, but increased ingoing levels of nitrite increased the levels of nitrite during storage time. Cassens (1997) reported on the residual nitrite of meat products in the US and suggested that residual nitrite levels have been rapidly reduced compared to those in the last few decades; he also suggested that the addition of sodium ascorbate or sodium erythorbate reduced the risk of nitrosamine. Sebranek et al. (2012) reviewed "natural curing," a process using celery powder containing nitrate and starter culture to convert nitrite and recommended using appropriate celery and starter culture combinations to have a similar effect as with the conventional use of sodium nitrite.

Natural colorants to partially replace sodium nitrite

Thus, it is recommended that nitrite be replaced or its levels reduced by replacing the color-development function and storage-extension function of nitrite to satisfy consumers. Currently, many natural colorants from vegetables and fruits are used to substitute sodium nitrite to keep the cured color of processed meats. Furthermore, these natural colorants have consumer acceptance, antioxidant activity, and acceptable sensory flavor and color since consumers demand health-conscious products for natural and organic ingredients without synthetic preservatives (Bázan-Lugo et al., 2012). For this purpose, studies have been conducted using other natural materials such as red beet (Kang and Lee, 2003; Jeong et al., 2010), paprika (Rascón et al., 2011; Kim and Chin, 2018), tomato (Bázan-Lugo et al., 2012; Seo and Chin, 2016), anka rice (Liu et al., 2010), cactus pigment (Kang and Lee, 2008), and purple sweet potato flour (Ahmed et al., 2009).

Red beet. The pigment extracted from red beet has been used for color development of cured meat products. The combination of red beet and sodium nitrite was better than red beet alone for color stability, contributing to color stability of smoked sausage during storage (Jeong et al., 2010). The addition of red beet pigment might increase the red color and thus decrease nitrite in meat products (Kang and Lee, 2003). Kang and Lee (2008) reported that the combination of 30 ppm nitrite, 2% sodium lactate, and 0.2% *Opuntiaficus indica* pigment reduced the level of nitrite at about 70 ppm without any defects.

Paprika. Considering the antioxidant effect and color stability of paprika oleoresin, it might reduce or replace the content of sodium nitrite ($NaNO_2$). Kim and Chin (2018) reported that paprika powder (PP) was partially replaced with sodium nitrite (Control). They used 2 cooking methods (boiling vs. smoking) and observed that the addition of PP in sausage manufacture increased redness values to levels similar to those with 150-ppm nitrite. Boiled LFSs containing 37.5-ppm sodium nitrite with PP at either 0.5% or 1.0% and those containing 150-ppm sodium nitrite had similar redness (a*) values. Paprika oleoresin, a carotenoid pigment, has been used as a coloring additive in various food industries (Rascón et al., 2011). Since it has high color stability due to high carotenoids, it is enough to represent the coloring effect of paprika (Pérez-Gálvez et al., 2003). Paprika oleoresin is processed to preserve its color, flavor, and taste and has higher pigment stability than paprika fruit (Lee et al., 2002). Therefore, paprika might be suitable as a natural color substance to reduce the amount of nitrite added because it can increase the redness (a*) values of meat products and improve their shelf-life.

Other natural colorants. In addition to paprika, tomato has been used for the partial replacement of sodium nitrite in processed meats. Bázan-Lugo et al. (2012) reported that the addition of tomato paste reduced nitrite levels from 150 to 100 ppm. They reported that paprika or tomato paste incorporation improved redness and the strength of meat batter. Seo and Chin (2016) reported that the redness values of LFSs containing 75-ppm nitrite, 1% pressed cherry fruit extract, and 0.5% tomato powder were similar to those with 150-ppm sodium nitrite. Therefore, to develop low-nitrite meat products, sodium nitrite should be replaced with natural coloring replacements that can facilitate color development, inhibit the growth of *C. botulinum*, and improve sensory attributes and shelf-life.

Functional Ingredients

Functional food is defined as food containing bioactive compounds such as antioxidants and antimicrobial and immune-promoting compounds and those that prevent disorders as well as have high nutritional value. Functional ingredients are responsible for the making of functional foods (Jiménez-Colmenero et al., 2001). They are classified based on 3 different basic requirements: (1) naturally occurring, (2) being consumed as a part of a daily diet, and (3) being involved in regulating specific processes for human health. For meat products, natural antioxidant and antimicrobial ingredients meet consumers' demands (Jiménez-Colmenero et al., 2001; Zhang et al., 2010). Meat is a good source of protein, fat, and other nutrients, such as several vitamins and minerals. The nutrients of meat could be improved by potential health-promoting natural ingredients, which might exceed conventional products, especially in terms of bioactive compounds (Decker and Park, 2010).

Natural antioxidants

Paprika (*Capsicum annuum* var. *Angulosum*) is an annual plant of *Solanaceae Capsicum* and *Annuum*. It has considerable amounts of antioxidants, such as vitamin C and E, tocopherol, and carotenoids that could prevent serious diseases such as cancer (Daood et al., 2006). In addition, carotenoids can be extracted from red, purple, and yellow colored pigments in paprika and have been widely used in various foods. Shim and Chin (2013) reported that the addition of PP reduced the thiobarbituric acid reactive substance values of ground pork and that increased level of paprika increased antioxidant activity of pork patties during storage. However, the thiobarbituric acid reactive substances were not different from the color of paprika (red vs. orange).

Bokbunja (*Rubus coreanus* [RC]) has been used as an antioxidant agent in several meat products. Park and Chin (2007) extracted RC with methanol and water and concluded that both solvents were useful to extract the RC. RC was added to pork patties and physicochemical properties of pork patties were measured during storage. Patties containing RC extended their shelf-life during 10 d of storage time. However, more than 3% of RC into patties might be negatively affected by having their color darkened. Rey et al. (2005) reported that cloud berry (*Rubus chamaemours*) retarded thiobarbituric acid values of pork patties, resulting in strong antioxidant activity of RC.

Garlic and onion can be used to enhance meat cuts. Loin and belly cuts with the addition of a 10% brine solution of onion and garlic had as much antioxidant activity as sodium ascorbate and had inhibited growth of *Enterobacteriaceae* (Park et al., 2008). The addition of garlic and onion reduced the oxidative products, especially volatile compounds and hexanal. Park and Chin (2010a) studied 2 garlic powder samples (fresh vs. heated) with 2 solvents (water and ethanol) and reported that the heated garlic sample had lower yield and water extract compared to fresh onion and that the methanol extract from the heated onion could be used as a natural antioxidant. They also evaluated the antioxidant activity of an ethanol extract of onion or garlic with preheating (100°C/30 min), which might change the composition, consequently either increasing or decreasing the bioactive activities. Both ethanol extracted garlic and onion powder inhibited the formation of hydroxylperoxide in a linoleic acid emulsion system. Antioxidative activities of garlic and onion extracts were not affected by preheating (Park and Chin, 2010b).

Min et al. (2010) measured antioxidant activities of garlic stem and red cabbage and reported that antioxidant activities of ethanol extracts of garlic stem were lower than those of red cabbage. In addition, pork patties with 0.5% garlic stem added to them had higher antioxidant activity than those with 0.5% red cabbage added. Therefore, they concluded that garlic and red cabbage could be used in meat products for their antioxidants. Kim and Chin (2011) dried tomatoes in a dry oven at 60°C and separated water-soluble and -insoluble tomato powders, added them to pork patties, and measured lipid oxidation during refrigerated storage. Pork patties containing dried tomato powder inhibited lipid oxidation during storage; however, the antioxidant activity of the pork patties containing 0.5% dried tomato powder did not differ from that of the reference (0.01% butylated hydroxytoluene). Two years later, Kim and Chin (2013) reported that the addition of tomato powder into pork sausages extended their shelf-life by inhibiting lipid oxidation during refrigerated storage.

Park et al. (2012) evaluated the antioxidant activity of yacon (*Polyminia sonchifolia*) pressed extracts or ethanol-extracted yacon and reported that the ethanol-extracted yacon had similar total phenolic compounds to those with yacon pressed extracts. They also reported that yacon pressed extracts added to pork patties retard lipid oxidation during storage. They concluded that yacon pressed extract could be used to inhibit lipid oxidation of processed meats during refrigerated storage.

Piccolella et al. (2008) reported on the antioxidant activity of methanolic or methyl acetate extracts from *Pruns yedoensis*, and they found that epicatechin-3-malate and epicatechin-3-(1”-methyl)malate might have antioxidant activity. Kirakosyan et al. (2009) reported that anthocyanins such as cyanidin and total phenolic compounds might affect antioxidant activity. Cyanidine and its derivatives, kaempferol, quercetin, and mealtonin, significantly contributed to antioxidant activity. Lee and Chin (2012) reported that water and ethanol extracts of red beet had antioxidant activity and applied them to pork patties as a natural antioxidant during storage. Choi et al. (2013) found that the addition of methanolic extract of cherry (*P. yedoensis*) reduced the lipid oxidation of pork patties during storage.

Digested muscle proteins have several functional properties since digestion with certain proteases might generate several functional peptides. Park and Chin (2011) evaluated the antioxidant activity of pepsin-digested water-soluble protein and SSP extracted from pork ham and found that the oxidative activity of linoleic acid is inhibited after the addition of 0.5% water-soluble protein and SSP hydrolysate.

Conclusions

Meat and meat products contain many nutrients, including protein, fat, and various minerals and vitamins. If some ingredients can be incorporated into the manufacture of meat products, they can not only increase nutritional value, but also increase economic value. However, for consumers, the minimum amount of key ingredients that might contribute to desirable physicochemical and textural properties and sensory characteristics of flavor, taste, and texture should be added. In addition, functional ingredients, extracted from various natural resources, can be also added to increase bioactive compounds that might prevent or sometimes cure certain diseases after being consumed for a long time. Thus, the addition of minimum amounts of the necessary ingredients combined with appropriate levels of functional ingredients in meat products is recommended so that consumers can have their health concerns met.

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