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Review

Use of phosphates in meat products

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Phosphates offer a range of possibilities when used in meat and poultry productions. Food grade phosphates are used in meat products for several reasons such as changing and/or stabilizing of pH-value, increasing water holding capacity in order to lead to higher yields, decreasing losses of weight in cooking, improving texture and sensory properties (tenderness, juiciness, color and flavor), extending shelf-life, etc. In addition, phosphates in meat products are also sources of the supply of phosphorus for consumers through diet, which is an essential mineral for the lives of humans. This review is focused on phosphates' properties, functions, application in meat and poultry products as well as influence on health.

Key words: Monophosphate, diphosphate, polyphosphate, texture parameters, water holding capacity, yield, meat.

INTRODUCTION

The use of food additives has become more prominent in recent years due to the increased production of prepared, processed and convenient foods (USDA, 2008). Additives are used for technological purposes in the manufacturing, processing, preparation, treatment, packaging, transportation or storage of certain foods, or may be reasonably expected to result in them or their by-products, thereby becoming directly or indirectly a component of such foods (Directive No 95/2/EC, 2006). Thus, food additives are widely used and are essential in food manufacturing industries.

Proteins, water, lipids, carbohydrates and minerals are the main components of meat. In living muscles or directly after slaughtering, proteins fix water and meat are compact and juicy. The adenosine triphosphate (ATP) which is present in meat allows the proteins of meat to keep opened structure. A few days (or a few hours for poultry meat) after slaughtering, the muscles get contracted and meat becomes exudative, water retention capability and organoleptic properties are altered (Hourant, 2004). Hence, in the processing of meat and meat products, food grade phosphates are one of the food additives and they are essential for several reasons such as increasing pH, increasing water holding capacity (WHC; structure of muscle protein is opened) in order to lead to higher yields and stabilized meat emulsions, decreasing cooking losses of weight, improving texture and sensory properties (tenderness, juiciness, color, flavor), extending shelf-life, etc. (Knipe, 2003; Lampila and Godber, 2002; Molins, 1991).

SELECTED PROPERTIES OF PHOSPHATES IN FOODSTUFFS

Phosphates used in meat processing industries are the salts of phosphoric acid and sodium or potassium. Phosphates are polyvalent ions which can form structures containing from one to hundreds or even thousands of phosphate tetrahedra (Lampila and Godber, 2002). Depending on the number of P atoms in the molecule, the usual name will change as follows: (i) one phosphorus atom $(PO_4)^3$ monophosphates (formerly orthophosphates); (ii) two phosphorus atoms $(P_2O_7)^{4-}$ diphosphates (formerly pyrophosphates); (iii) three phosphorus atoms $(P_3O_{10})^{5-}$ tripolyphosphates; and more than three phosphorus atoms $(P_nO_{3n+1})^{(n+2)-}$ polyphosphates (Hourant, 2004).

There are two basic forms of phosphates: ring

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phosphates and chain phosphates (linear phosphates). In most countries, only chain phosphates (linear) are permitted to be used in food processing industries. Ring phosphates are mainly used in the other industries such as those for water treatment, metal cleaning, and detergents production (Feiner, 2006). The selected properties such as the formula, pH, solubility, E-code (for food additives) and relative content of P_2O_5 (in %) are presented in Table 1.

ROLES OF PHOSPHATES IN MEAT AND MEAT PRODUCTS AND LAW REGULATIONS

Phosphates used in meat and meat products have several functions, especially functions such as the adjustment of pH, buffer properties, sequestration of selected cations, changing the ionic charges distributions, changing the ionic strength of environment and/or bacteriostatic effects.

Different individual phosphates show significant differences in pH values (Table 1). Nearly all phosphates, as well as their blends which are used in meat are alkaline phosphates and their addition to slightly sour meat leads to a rise in pH inside the meat product. When a movement further away from the isoelectric point (IEP) takes place, it enhances the water binding capacity of proteins because greater electrostatics repulsive forces create large gaps between actin and myosin and larger amounts of added water can be bound (Anjaneyulu et al., 1990; Feiner, 2006; Lampila and Godber, 2002; Puolanne et al., 2001; Young et al., 2005).

Mixtures of monophosphates (MSP, DSP and TSP) are excellent buffers; diphosphates could also be signed as buffers, but chains longer than two phosphorus atoms are not good buffers at all (Lampila and Godber, 2002; Molins, 1991). Buffering property helps meat retain and protect fresh color by changing the pH of meat after slaughtering (Lampila and Godber, 2002).

Sequestration of metal ions such as Ca^{2+}, Mg^{2+}, Fe^{2+}, Fe^{3+} etc, which are present in meat, by condensing phosphates to form a complex is an important function of phosphates in food applications (Lampila et al., 2002). Binding of phosphates with Ca^{2+}, Mg^{2+} (cross-bridges in actomyosin complex) contribute to separate actin and myosin after rigor mortis. Hence, the above mentioned process will enhance the water holding capacity of meat and meat products, improve the degree of tenderness and color of meat. Moreover, the binding of metal ions could reduce oxidative rancidity (Feiner, 2006; Fernández-López et al., 2004; Inklaar, 1967; Lampila and Godber, 2002; Molins, 1991).

Phosphates as polyelectrolytes are able to change the ionic charges distributions. Thus, the addition of phosphate increases the ionic strength of the meat and consequently, an increased ionic strength leads to a more severe degree of swelling of the muscle fibers and activation of protein. Enhanced levels of activated and swollen protein support the immobilization of the water added to meat products and the emulsification of fat (Feiner, 2006; Offer and Trinick, 1983; Shu Qin et al., 2009; Siegel and Schmidt, 1979; Trout and Schmidt, 1986).

Salts have a major effect on ionic strength, and could extract myosin from myofibrillar structures in meat. Salts could enhance swelling of the protein structure but they (on their own) do not solubilize much protein (Knight and Parsons, 1988; Ranken, 2000). On the other hand, phosphates on their own hardly activate proteins; they can only remove the link between actin and myosin (Feiner, 2006). Thus, through the addition of salts together with phosphates at the same time to a meat product, the muscular protein becomes soluble and solubilized, or activated; and the solubilized protein can immobilize high levels of added water as well as emulsify a large amount of fat (Bendall, 1954; Fernández-López et al., 2004; Huffman et al., 1981; Lampila and Godber, 2002; Moore et al., 1976; Shults and Wierbicki, 1973; Zayas, 1997).

Phosphates are slightly bacteriostatic as it slows down the growth of some gram-positive bacteria. Phosphates are not considered as direct preservatives. They only can impart some desirable properties when used as acidulants or in combination with other food ingredients such as nisin, EDTA, NaCl, nitrites, erythorbate, etc; can inhibit gram-positive bacteria such as *Leuconostoc carnosum*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Bacillus cereus*, *Bacillus stearothermophilus*, *Bacillus brevis*, *Bacillus subtilis*, *Bacillus sphaericus, Bacillus sp.*, *Micrococcus luteus*, *Corynebacterium glutamicum*; and have a little effect on gram-negative bacteria such as *Salmonella typhimurium*, *Salmonella enteritidis, Escherichia coli* (Buňková et al., 2008; Dickson et al., 1994; Feiner, 2006; Lampila and Godber, 2002; Molins, 1991; Molins et al., 1985; Sofos, 1986; Tompkin, 1984).

There are some important factors that influence the choice of appropriate phosphate mixtures in meat processing industries, such as solubility, pH value of products and its effect on muscular proteins. Solubility must be considered because phosphates differ in solubility (Table 1). Many phosphates are not easily soluble in most marinade solutions. Therefore, phosphates are typically dissolved at room-temperature water before adding salt and then chilled before use (Alvarado and McKee, 2007). When preparing ham brine using ice cold water, the phosphates must also dissolve quickly and completely (Feiner, 2006).

Monophosphates are commonly used for the adjusting and buffering of pH values; however, on their own they have a small effect on the muscular protein (Feiner, 2006). Thus, monophosphates are not applied alone in meat products.

The most functional phosphates are diphosphates

Table 1. The list of phosphates commonly used in meat products and some properties of phosphates [a].

Common names	Abbreviation	Formulas	pH (1% solution)	Solubility (g/100g H_2O)	E number [b]	$\%P_2O_5$ [c]
Sodium monophosphate						
Monosodium phosphate	MSP	NaH_2PO_4	4.4	85 (20°C)	E 339(i)	59.2%
Disodium phosphate	DSP	Na_2HPO_4	8.8	7.7 (20°C)	E 339(ii)	50.0%
Trisodium phosphate	TSP	Na_3PO_4	12	13 (20°C)	E 339(iii)	43.3%
Sodium diphosphate (tetrasodium pyrophosphate)	TSPP	$Na_4P_2O_7$	10.2	6 (20°C)	E 450(iii)	53.4%
Disodium diphosphate (sodium acid pyrophosphate)	SAPP	$Na_2H_2P_2O_7$	4.2	12 (20°C)	E450(i)	64.0%
Sodium tripolyphosphate (pentasodium phosphate)	STPP	$Na_5P_3O_{10}$	9.8	15 (20°C)	E 451(i)	57.9%
Sodium hexametaphosphate [d]	SHMP	$(NaPO_3)_n$		High soluble	E 452(i)	69.6%
(Graham's salt)		n = 10-15	6.2			
		n = 50-100	7.0			
Potassium monophosphate						
Monopotassium phosphate	MKP	KH_2PO_4	4.4	20 (20°C)	E 340(i)	52.1%
Dipotassium phosphate	DKP	K_2HPO_4	9.5	120 (20°C)	E 340(ii)	40.8%
Tripotasium phosphate	TKP	K_3PO_4	12	51 (20°C)	E 340(iii)	33.4%
Potassium diphosphate (tetrapotassium pyrophosphate)	TKPP	$K_4P_2O_7$	10.4	180 (20°C)	E 450(v)	43.0%
Potassium tripolyphosphate	KTPP	$K_5P_3O_{10}$	9.6	178 (20°C)	E 451(ii)	47.5%

[a] Adapted from Lampila et al. (2002).
[b] Adapted from Council Directive No 95/2/EC (2006).
[c] $\%P_2O_5$ was calculated by the P_2O_5 content of a phosphate and is expressed as a percentage.
[d] Modified from Molins (1991).

(especially tetrasodium diphosphate - TSPP) because they act on the actomyosin complex of meat protein right away and have a high pH value. The use of TSPP results in higher protein solubility which induces good water-binding ability of proteins in comparison with the application of polyphosphates (Molins, 1991; Zayas, 1997). On the other hand, solubility of TSPP is low (Table 1). Therefore, longer-chain phosphates such as STTP and SHMP are commonly used as a blend to improve and optimize solubility and functionality in a variety of meat product formulations (Alvarado and McKee, 2007; Anjaneyulu et al., 1989; Molins, 1991; Offer and Trinick, 1983). A phosphate blend utilized for emulsified sausages contains predominantly short-chain phosphates as required in such an application for improving sausage emulsion water holding capacity and stability (Feiner, 2006; Zayas, 1997).

Sensory properties of products should be taken into account while choosing appropriate phosphate mixture content. Phosphate flavor is usually considered as unpleasant. The concentration of 0.3 to 0.5% could lead to products with unacceptable bitter taste (Ranken, 2000).

Food phosphates, used in meat and meat products, must be manufactured according to good manufacturing practices (GMP). The U.S. Food and Drug Administration have classified the food phosphates as generally recognized as safe (GRAS) when used in accordance with GMP (Code of Federal Regulations, 2003). Phosphates are not permitted in fresh meat but could be added to meat preparations, minced meat and meat products (Regulation EC No 853/2004, 2004). The maximum permitted level of phosphates in meat and meat products according to European legislation is 5 g/kg as phosphorus peroxide (P_2O_5) individually or in combination to the finished product (Directive No 95/2/EC, Rev. 2006). According to FAO/WHO food standards, the maximum permitted level of phosphates (singly or in combination) is: (i) 2200 mg/kg as phosphorus (approximately 5041 mg/kg expressed in P_2O_5) in the finished product as frozen processed poultry meat and game products, in whole pieces or cuts and in processed comminuted meat, poultry and game products (Codex Stan192-1995, Rev. 2010); (ii) 3000 mg/kg as P_2O_5 in the finished product as luncheon meat (Codex Stan 089-1981, Rev. 1991), in cooked cured ham (Codex Stan 096-1981, Rev. 1991), in cooked cured pork shoulder (Codex Stan 097-1981, Rev. 1991) and in cooked cured chopped meat (Codex Stan 098-1981, Rev. 1991).

INFLUENCE OF PHOSPHATES ON HEALTH

Phosphorus is responsible for many biological properties and functions. It is present in DNA, RNA, enzymes, etc. and especially co-exists with calcium and magnesium forms in bones. Generally, phosphorus is needed for the growth, maintenance and repair of all tissues and cells of living organisms. According to Institute of Medicine recommendation, the recommended dietary intakes (RDIs) of phosphorus depend especially on the age of people and/or some special status: (i) 0 to six months, 100 mg/day; (ii) seven to 12 months, 275 mg/day; (iii) one to three years, 460 mg/day; (iv) four to eight years, 500 mg/day; (v) nine to 18 years, 1,250 mg; (vi) adults (> 19 years), 700 mg/day; (vii) pregnant or lactating women 14 to 18 years, 1,250 mg/day and older than 18 years, 700 mg/day (Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, 1997).

Several studies which focused on the effect of the addition of phosphates on consumer health have been published and these studies have given contradictory results. The kidneys easily control the blood phosphorus level and efficiently excrete any excess of phosphorus; hence, up to now, there is no evidence that higher phosphate intakes are detrimental to bone health or to bone calcium excretion in the urine in healthy adults not having problems with kidneys (Fenton et al., 2009; Whybro et al., 1998). However, in the study of Huttunen et al. (2006) with adult rats, excessive intake of dietary phosphate without the company of calcium caused rise in concentration of serum parathyroid hormone and hindered mineral deposition into cortical bone, leading to lower bone mineral density. Generally, to avoid potential adverse risks on health, Standing Committee on the Scientific Evaluation of Dietary Reference Intakes (1997) has recommended a tolerable upper intake levels (ULs) for adults, 4 g per day of phosphorus.

THE EFFECT OF PHOSPHATE APPLICATION ON SELECTED PROPERTIES OF MEAT PRODUCTS

Bendall (1954) evaluated the effect of 0.25 and 0.50% of diphosphate in 1% sodium chloride solution (overall concentrations) on the volume increase of the mince rabbit muscle. The addition of: (i) 1% sodium chloride solution led to the volume increase of 120.0 ± 6.0%; (ii) 1% sodium chloride solution/0.25% diphosphate led to the volume increase of 151.0 ± 14.0%; and (iii) 1% sodium chloride solution/0.5% diphosphate led to the volume increase of 164.0 ± 14.0% (expressed as the percentage of untreated fresh muscle). The cooked volumes were 171.0 ± 4.0% (1% sodium chloride solution), 189.0 ± 8.0% (1% sodium chloride solution/0.25% diphosphate) and 199.0 ± 6.0% (1% sodium chloride solution/0.5% diphosphate).

Restructured meat products are small pieces of meat reformed into steaks, chops and/or roast-like meat products. Minced, flaked, diced or mechanically recovered meat may be used to produce restructured meat (IFIS, 2005). Schwartz and Mandigo (1976) studied the effect of salt, STPP, and storage on the restructured pork. The results indicate that the combination of salt and STPP (0.75 and 0.125%, respectively) on restructured pork after four weeks storage at -23°C, improved color, aroma, flavor, eating texture, cooking loss, and increased water holding capacity and juiciness rating.

Wierbicki and Howker (1976) studied the effect of NaCl, phosphates (STPP, equivalent amounts of TSPP – expressed in % P_2O_5) and other curing ingredients on the shrinkage of lean pork meat and the quality of smoked processed ham. NaCl (1 to 10%), STPP (0.15 to 0.90%), equivalent amounts of TSPP (expressed in % P_2O_5), 0.015% $NaNO_2$, 0.06% $NaNO_3$, 0.0275% sodium ascorbate and 0.0275% sodium erythorbate were used in this study. The results show that the curing ingredients $NaNO_2$, $NaNO_3$, sodium ascorbate and sodium erythorbate have little effect on meat shrinkage; the addition of either 0.3% STPP or 0.217% TSPP with 3% salt decreased the meat shrinkage to 5% and no significant effect on the meat shrink was observed by increasing the addition of STPP above 0.3%. Cut-and-formed smoked, cured ham containing 3% salt, either 0.3% STPP or 0.217% TSPP and the other curing ingredients was as acceptable as the ham with either 0.5% STPP or 0.362% TSPP. Therefore, in cured hams, STPP can be used in 0.3% concentration.

Anjaneyulu et al. (1989) studied the effect of the additions of NaCl, polyphosphates and their blends on the physicochemical properties of buffalo meat and patties. In this study, along with 2% NaCl, concentrations of phosphates (TSPP, STPP, SHMP, sodium acid diphosphate (SAPP)) and their blends at 0.3, 0.5 and 0.7% were evaluated. The results indicate that the order of effect of phosphates and their blends at all concentrations was TSPP > STPP > SHMP. The individual usage of SAPP and SHMP had significantly little effects on improving the quality of meat such as increased pH, WHC, emulsifying capacity, extractability of salt soluble proteins, color of ground meat, decreased cooking loss, improved emulsion stability, enhanced yield, texture and moisture retention of cooked patties. Blends containing two phosphates: 90% TSPP + 10% SHMP and 75% TSPP + 25% STPP were relatively more effective. And a phosphate blend consisting of 65.0% TSPP, 17.5% STPP and 17.5% SAPP was equally effective like that of TSPP in improving the functionality of hot and chilled meat and had the advantage of reducing the amount of sodium up to 3%. Again, Anjaneyulu et al. (1990) studied the effect of the blends of phosphate on the functional properties and yield of buffalo meat patties. Samples in this study included phosphate blends of 0.5% (including 65.0% TSPP, 17.5% STPP, and 17.5% SAPP) + NaCl 2%, NaOH 0.5% (used to adjust the pH to equal that of the phosphate treatment) + NaCl 2% and control without either NaCl or added polyphosphate. The results show improved emulsifying capacity; increased emulsion stability, yield of patties and WHC; and reduced cook-cool loss and shrinkage of patties as the consequence of the treatments in the following sequence: phosphate blends > NaOH pH adjustment > control. It affirmed that the effect of polyphosphate is not only for a pH effect.

Moiseev and Cornforth (1997) studied the effect of NaOH and STPP on bind strength and sensory characteristic of restructured beef rolls. Various levels of added water (0, 5 and 10%) and three types of ingredients were used: (i) 1% NaCl (control); (ii) 1%NaCl + 0.375% STTP and (iii) 1% NaCl + 0.07% NaOH. The results show that with either 5 or 10% added water, there were no differences in the juiciness of NaOH and STPP rolls, but both were juicier than controls. However, STPP rolls with 20% added water had higher juiciness score than either NaOH rolls or controls. The overall acceptability of STPP rolls was higher than NaOH rolls at 5 and 20% added water, but at 10% added water there was no significant difference in the acceptability of NaOH and STPP rolls. The strength of water-binding and cooked yield of samples was improved as follows: STPP > NaOH > control. These results confirm that STTP did not only increase the pH value but also strongly increased the extraction of protein in meat.

Color of meat could be measured by the Hunter L*a*b* color reflectance measurement system. In this measurement system, the L* value (0 and 100) represents the difference between white and black; the a* value (+50 and -50) represents the green (+50) to red tone (-50); the b* value (-50 and +50) represents the blue (-50) to the yellow tone (+50) (Feiner, 2006; HunterLab, 1996; HunterLab, 2000).

Lee et al. (1998) studied the effect of sodium phytate (SPT), TSPP, and STPP on physico-chemical characteristics of restructured beef. The four samples which included: (i) 1% NaCl (control); (ii) 1% NaCl + 0.5% TSPP; (iii) 1% NaCl + 0.5% STPP; and (iv) 1% NaCl + 0.5% SPT were studied. The results show that the SPT, TSPP, and STPP increased pH in raw beef stored for one day at 4℃ and in the cooked beef. In the raw beef, salt-soluble protein level was as follows: STTP > SPT > TSPP > control. In the cooked beef, increase of bind strength, cook yield, moisture level was as follows: STPP > TSPP > SPT > control. SPT, TSPP, and STPP decreased L* value and b* value; and increased a* value in the raw beef but had no effect on the color values in the cooked beef.

Sheard et al. (1999) studied the injection of polyphosphate solutions into pork to improve juiciness and tenderness after cooking. Two injection levels (5 and 10%) and three concentrations of STPP (0, 3 and 5%) were used in 64 pork loin samples to assess the influence of STPP injection on the eating quality of pork steaks cooked by grilling to a centre temperature of 72.5 or 80.0℃. The results of sensory evaluation in this study show that pork steaks containing 5% STPP, injection level 10% and cooked to 80℃ were tenderer than, but as juicy as steaks without STPP.

Torley et al. (2000) studied the effect of ionic strength, polyphosphates type, pH, cooking temperature and preblending on the functional properties of normal and pale, soft, exudative (PSE) pork. With TSPP (0.35%) and STPP (0.37%), it was noted that the ionic strength, pH and addition of polyphosphates had much smaller effects on the functional properties of PSE pork than in normal pork meat. Added polyphosphate only gave a lower cook loss though the texture was still inferior.

Capita et al. (2000) studied the effect of trisodium phosphate solutions washing on the sensory evaluation of poultry meat. In this study, chicken thigh samples were dipped in TSP solutions (8, 10 and 12%) with the ratio 1:4 (w/v) at 20℃ temperature for 15 min; after that, the samples were stored at 2℃ until the sensory tests were performed; the sampling days were at day 0 (the day of slaughter, collection and treatment) for raw thighs and day seven of storage at 2℃ for raw and cooked thighs. The results indicate that the scores of sensory quality evaluation of 10 and 12% sample were higher than those of the control sample in day 0: better smell and color (chicken thighs dipped in 10% TSP) and better color and overall acceptability (chicken thighs dipped in 12% TSP). However, there were no significant differences between the sensory characteristics of control or treated raw samples after seven days storage apart from the color, flavor and overall acceptability of thighs dipped in 12% which were rated significantly lower than the control sample. These results suggested that TSP solutions have good potential as dips to sanitize chicken carcasses.

Puolanne et al. (2001) studied the combined effects of sodium chloride and raw meat pH on WHC in cooked sausage with and without added phosphate. In this study, beef and pork with varying natural post-rigor pH-value ranges (pork: 5.50 to 6.12 and beef: 5.60 to 6.48) were used as mixtures, and 0.5 to 2.5 % NaCl was used with or without added commercial sausage phosphate (2.5 g/kg determined as P_2O_5). The results show that high pH value and added salt increased WHC in pork and beef meat. The pH-value of raw meat materials for the maximum water-holding was 6.3. Maximum in water-holding was reached in 2.5% NaCl in all pH-values, both with and without added phosphate. When phosphate was added, the pH value of sausage increased approximately 0.5 to 0.7 units. On the other hand, when salt was added, pH value decreased about 0.1 pH unit per 1% NaCl. The same water-holding as with 2.5% NaCl in pH 5.7 can be reached with 1.5% NaCl in pH 6.1 with increased pH of the batter. In sausages with a reduced content of NaCl, the pH of the batter should be increased by using high-pH meat mixtures and/or pH-raising phosphates in order to reach a high enough level of water-holding.

Hsu and Chung (2001) studied the effect of kappa-carrageenan, salt, phosphate, and fat on the qualities of low fat emulsified meatballs (Kung-wans). Kappa-carrageenan (0 to 2%), salt (1 to 3%), polyphosphate (mixture of sodium polyphosphate and sodium diphosphate, 1:1 ratio, w/w, 0.0 to 0.4%) and pork-back-fat (0 to 10%) were used in this study. The results indicate that fat addition (0 to 10%) did not have a significant effect on the measured qualities of low fat Kung-wans. Kappa-carrageenan addition significantly affected product cooking yield, hardness, adhesion, chewiness, gummi-ness and viscosity. Polyphosphate addition showed significant effects on product cooking yield, diameter, lipid content, adhesion, viscosity and a* value (Hunter system - mentioned earlier). Salt addition levels had significant effects on product cooking yield, diameter, lipid content, cohesiveness, brittleness, gumminess and viscosity. The combination of salt and polyphosphates had significant effects on the product's texture and overall acceptance. Addition levels of salt, polyphos-phates and kappa-carrageenan at around 2.7, 0.17 and 2% respectively, produced products that were more acceptable.

The combination of dextrose and tripolyphosphate with 2% salt to improve tenderness of lamb carcasses was studied by Murphy and Zerby (2004). In this study, each carcass was randomly assigned to one of the following: (i) deionized water (H_2O); (ii) 2% NaCl (S); (iii) 3% dextrose (D); (iv) 0.5% STPP (P); (v) 2% NaCl + 3% dextrose (SD); (vi) 2% NaCl + 0.5% STPP (SP); (vii) 0.5% STPP + 3% dextrose (PD), and (viii) 2% NaCl + 0.5% STPP + 3% dextrose (SPD). The results show that the use of SD, SP and SPD solutions all improved tenderness, decreased cook loss and increased ultimate pH when compared with the others and had no adverse effects on microbiological growth when stored at 0 to 4°C for six days. Meanwhile, a sample of S solution moderately decreased cook loss, but H_2O, P and D solutions did not; and the use of H_2O, P, D, and S solutions also slightly improved tenderness, but increased the growth of microorganisms.

Fernández-López et al., (2004) and Moiseev and Cornforth (1997) studied the effect of NaCl, STPP and pH on the color properties of pork meat. The effect of different pH values (4, 5, and 6), different concentrations of NaCl (none, 1.5, and 3%) and of STPP (none, 0.15, and 0.3%) were used in this study. For the pH levels (4, 5, and 6), either 1 M of lactic acid or 1 M of NaOH was added to the pork meat. The results indicate that when increasing the addition NaCl or STPP, WHC rose, lightness (L*) fell but a* and b* value rose compared to control (without either NaCl or STTP); WHC of samples with added STTP was higher than those with added NaCl. On the other hand, pH value fell with an increased NaCl while it rose with an increased STTP. A decrease in the pH of meat increased L* and b* value but decreesed a* value and WHC. However, a lower pH and the addition of NaCl or STPP led to an increase in the metmyoglobin percentage.

The effect of enhancement with phosphates at different injection rates along with 2% NaCl on color, quality, and sensory characteristics of beef was studied by Baublits et al. (2005a, b). In these studies, varying phosphates such as STPP, SHMP, and TSPP at the concentrations 0.2 and 0.4% with rates of injection (12 and 18%) along with 2% NaCl were used. The results indicate that STPP was the most effective phosphate type for maintaining the color of beef in concentration 0.4% at the rate of injection 18% (Baublits et al., 2005b). SHMP, STPP, and TSPP were all evaluated as causing more tenderness and juiciness ($P < 0.05$) by sensory panelists in steaks than the enhancement done only with sodium chloride 2%, but STTP or TSPP in 0.4% with the injection rate 18% can improve sensory tenderness perceptions without decreasing product yields (Baublits et al., 2005a).

With the same conditions mentioned earlier, Baublits et al. (2006) studied the effect of enhancement with varying phosphate types, concentrations, and injection rates without sodium chloride on color, quality and sensory characteristics of beef. When the samples were without sodium chloride, all the three samples with phosphate types maintained higher L* values than untreated steaks (CNT) through five days-of-display, and SHMP had higher L* values than STPP and TSPP through seven days-of-display; but steaks enhanced with TSPP had higher a* values than CNT on days five and seven of display, whereas SHMP or STPP enhanced steaks generally had similar a* values as CNT after three days of display; no differences were observed between 12 or 18% injection rates. Thus, only steaks enhanced with TSPP were redder, more vivid, and had higher oxymyoglobin proportions with 0.4% concentration (Baublits et al., 2006b). On the other hand, the three phosphate types (SHMP, STPP and TSPP) with different concentrations did not improve sensory tenderness or juiciness compared to untreated muscles, but enhancement at an 18% pump rate improved overall tenderness. These results show that phosphates enhancement independent of sodium chloride generally did not improve water retention, cooked yields and palatability compared to untreated samples (Baublits et al., 2006a).

Sen et al. (2005) studied the effect of chilling, polyphosphate and bicarbonate on quality characteristics of broiler breast meat. The experiment with pre-chill and post-chill breast meat, treated with: (i) 3% TSPP; (ii) 3% sodium bicarbonate + 2% NaCl; (iii) 2% NaCl alone (control) was carried out; and the treated samples were stored at 4°C for 24 h. The result of the treatment with phosphate and bicarbonate plus NaCl increased pH in both the pre- and post-chill groups; and treated breasts exhibited lower L* and higher a* value (that is, appeared redder) than controls. However, the sample treated with TSPP had a smaller effect than the sample treated with sodium bicarbonate plus NaCl.

Ünal et al. (2006) investigated the effects of temperature on phosphate diffusion mechanism in meat samples dipped in different concentrations of STPP (0 to 6%) at different temperatures (18 to 36°C). The results indicate that when the concentration of STPP solutions increased, the phosphate concentration in the beef samples also rose, and the diffusion was found to be strongly temperature dependent, that is, increased temperature caused an increase in the diffusion.

Barbut and Somboonpanyakul (2007) studied the effect of crude Malva nut gum (CMG) and phosphate on yield, texture, color, and microstructure of mechanically deboned chicken meat batters. In this study, mixtures of CMG (none, 0.2 and 0.6%) and STPP (none and 0.5%) were used. The results indicate that the batters with CMG or STPP or mixture of them all decreased cook and fat losses compared with the control batter. Hardness values of using the mixture of CMG and STPP provided were higher than those of the control batter; and hardness values of using CMG or STPP were lower than those of the control batter. The batter with 0.5% STPP and the batters with a mixture of CMG and STPP had higher springiness compared with batters with CMG alone or control sample. Increasing the CMG level to 0.6% reduced the lightness and redness of the cooked products.

Erdogdu et al. (2007) studied the effects of processing conditions (cooking time, STPP concentration and dipping time) on cook losses and textural properties of red meats. For this study, meat pieces (2 × 2 × 2 cm in size) were dipped in different concentrations of STPP solutions (2 to 6%) for 10 to 30 min, and were cooked in boiling water for 5 to 15 min. The results indicate that an increase in STPP concentration increased cohesiveness; an increase in cooking time resulted in higher hardness, gumminess, chewiness and cook losses, while an increase in dipping times decreased the cook losses and hardness. These results indicate that STPP concentration, STPP dipping and cooking times had significant effects on the changes of textural properties and cook losses of red meat.

Somboonpanyakul et al. (2007) evaluated the effect of CMG addition to poultry breast meat batters formulated with different salt levels and phosphate. The treatments which consisted of salt (0, 1, 2 and 3%), CMG (none and 0.2%) and STTP (none and 0.5%) were studied. The results show that the cooked batter with 2% NaCl and 0.5% phosphate showed the highest values for all of the textural parameters. However, the cohesiveness and chewiness were reduced by the addition of 0.2% CMG. Frankfurters with 0.2% CMG showed low cooking loss and had better textural properties than the frankfurters without CMG. However, frankfurters' lightness and redness were reduced due to the addition of CMG.

Shu Qin et al. (2009) studied the influence of marinading with polyphosphate on Simmental beef shear value and ultra structure. Polyphosphates were used to marinate beef at 5% disodium dihydrogen diphosphate (DSPP), 3% TSPP, 3% SHMP and 3% STPP for one to three days. By increasing the concentration and marinating time, the tenderizing effect of polyphosphates on meat samples changed as follows: TSPP ≈ SHMP > STPP > DSPP > control. The addition of polyphosphates decreased shear force significantly in comparison with controls. After marinating for three days, DSPP significantly increased the soluble collagen content compared with the other polyphosphates. TSPP and SHMP both disrupted the myofibrillar structure completely and myofibril bundles collapsed together. STPP disrupted the myofibrillar structure as well. TSPP dissolved the perimysium into collagen fibers and collagen fibrils which arranged loosely and looked like dispersed silk. The perimysium was separated into collagen fibers and collagen fibrils by STPP and SHMP, but the collagen fibrils were in close contact with each other. These results show that polyphosphates can make the soluble protein in meat to increase binding water and improve tenderness of meat.

Generally, many types of phosphates and their mixtures (phosphate blends) were examined in meat and meat products. The effects of the combination of phosphates and hydrocolloids were studied as well. At different concentrations and in combinations with other substances, phosphates increased uncooked meat volume, WHC, cooking temperature, soluble collagen; improved bind strength, emulsifying capacity, emulsion stability, yield of patties, tenderness, juiciness, color, sensory quality, textural properties, and decreased cooking-loss, shear force, shrinkage of buffalo patties and lean pork meat.

CONCLUSION

Phosphates are widely used in meat processing industry from poultry, chicken, pork, beef, etc. for roast beef, hams, frankfurters, fresh sausages, salami, etc. The usage of the appropriate amount and mixture of phosphates can lead to the improvement of some properties of final products, such as moisture retention, water holding, color protection, slowing down of oxidation, extension of shelf- life, stabilizing and enhancing structure of final products.

Under European legislation, phosphates are not permitted in fresh meat but could be added to meat preparations, minced meat and meat products. The permitted level of phosphates in meat and meat products is 5 g/kg expressed as phosphorus peroxide (P_2O_5) individually or in a combination in the finished product.

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