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Issue: *Dietary Phosphorus Excess and Health***Applications and functions of food-grade phosphates**

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Food-grade phosphates are used in the production of foods to function as buffers, sequestrants, acidulants, bases, flavors, cryoprotectants, gel accelerants, dispersants, nutrients, precipitants, and as free-flow (anticaking) or ion-exchange agents. The actions of phosphates affect the chemical leavening of cakes, cookies, pancakes, muffins, and doughnuts; the even melt of processed cheese; the structure of a frankfurter; the bind and hydration of delicatessen meats; the fluidity of evaporated milk; the distinctive flavor of cola beverages; the free flow of spice blends; the mineral content of isotonic beverages; and the light color of par-fried potato strips. In the United States, food-grade phosphates are generally recognized as safe, but use levels have been defined for some foods by the Code of Federal Regulations, specifically Titles 9 and 21 for foods regulated by the U.S. Department of Agriculture (USDA) and the U.S. Food and Drug Administration (FDA), respectively. Standards for food purity are defined nationally and internationally in sources such as the Food Chemicals Codex and the Joint Food and Agriculture Organization and World Health Organization (FAO/WHO) Expert Committee on Food Additives.

**Keywords:** phosphates; functions; ingredient; food grade

**Introduction**

Phosphate rock is mined all over the world with the largest reserves of high purity originating in Morocco.<sup>1</sup> The mined and crushed rock is reacted with sulfuric acid followed by a solvent extraction of the phosphoric acid and release into an aqueous phase. The acid is dearsenified and deflourinated, resulting in food-grade phosphoric acid (purified wet acid or PWA). Orthophosphates are manufactured by reacting phosphoric acid with the desired alkali ( $\text{Na}_2\text{CO}_3$ , NaOH, KOH, KCl,  $\text{CaCO}_3$ , and  $\text{NH}_3$ ) resulting in sodium, potassium, calcium, or ammonium phosphates. Condensation and elongation reactions to produce pyrophosphates, tripolyphosphates, and hexametaphosphates (glassy phosphates) have been well described.<sup>2</sup> As a rule, potassium phosphates are more water soluble than sodium salts and the calcium salts are acid soluble. Characteristics, including acronyms, of species commonly used in the food industry are described in Table 1.

The major food uses of food-grade phosphates include chemical leavening of cakes, cookies, pan-

cakes, waffles, and doughnuts; maintaining the structure and hydration of meat, poultry, and seafood products (muscle foods); use as a protein dispersant in evaporated and spray-dried milk products; use for either flavor or added minerals in beverages; and maintaining the natural structure of some canned fruit and vegetable products. Depending upon the application, phosphates may function as buffers, sequestrants, acidulants, bases, flavors, cryoprotectants, gel accelerants, dispersants, nutrients, precipitants, and as free-flow or ion-exchange agents. Food-grade phosphates have been reviewed extensively and in more detail on their properties and uses.<sup>2-6</sup> The uses and functions of food-grade phosphates will be briefly described by food commodity here.

**Meat, poultry, and seafood**

Sodium tripolyphosphate (STPP) is the primary nonchloride salt used in the processing of muscle foods. Approximately 20% of muscle food applications include the use of STPP in blends with sodium hexametaphosphate (SHMP, also known as sodium

**Table 1.** Common name, acronym, chemical formula, solubility in water, and pH of selected food-grade anhydrous phosphates

Phosphate	Acronym	Formula	Solubility (g/100 mL)	pH (1% solution)
Monosodium phosphate	MSP	NaH <sub>2</sub> PO <sub>4</sub>	80	4.4–4.8
Disodium phosphate	DSP	Na <sub>2</sub> HPO <sub>4</sub>	10	8.6–9.4
Trisodium phosphate	TSP	Na <sub>3</sub> PO <sub>4</sub>	12	11.9–12.5
Monopotassium phosphate	MKP	KH <sub>2</sub> PO <sub>4</sub>	33	4.4–4.8
Dipotassium phosphate	DKP	K <sub>2</sub> HPO <sub>4</sub>	167	8.6–9.4
Tripotassium phosphate	TKP	K <sub>3</sub> PO <sub>4</sub>	90	11.9–12.5
Monocalcium phosphate	MCP	Ca(H <sub>2</sub> PO <sub>4</sub> ) <sub>2</sub>	Min.	2.7–3.0
Dicalcium phosphate	DCP	Ca <sub>2</sub> HPO <sub>4</sub>	Insoluble	7.2–8.2
Tricalcium phosphate	TCP	Ca <sub>3</sub> (OH)(PO <sub>4</sub> ) <sub>3</sub>	Insoluble	7.0–8.0
Sodium acid pyrophosphate	SAPP	Na <sub>2</sub> H <sub>2</sub> P <sub>2</sub> O <sub>7</sub>	12	4.0–4.4
Tetrasodium pyrophosphate	TSPP	Na <sub>4</sub> P <sub>2</sub> O <sub>7</sub>	6.5	9.9–10.7
Tetrapotassium pyrophosphate	TKPP	K <sub>4</sub> P <sub>2</sub> O <sub>7</sub>	184	10.0–10.5
Sodium tripolyphosphate	STPP	Na <sub>5</sub> P <sub>3</sub> O <sub>10</sub>	15	9.5–10.2
Potassium tripolyphosphate	KTPP	K <sub>5</sub> P <sub>3</sub> O <sub>10</sub>	180	9.5–10.2
Sodium hexametaphosphate	SHMP	(NaPO <sub>3</sub> ) <sub>n</sub>	∞	6.3–7.3
Sodium aluminum phosphate	SALP	Na <sub>2</sub> Al <sub>2</sub> H <sub>15</sub> (PO <sub>4</sub> ) <sub>8</sub>	Min.	3.3–3.5
Monoammonium phosphate	MAP	NH <sub>4</sub> H <sub>2</sub> PO <sub>4</sub>	38	4.5–4.7
Diammonium phosphate	DAP	(NH <sub>4</sub> ) <sub>2</sub> HPO <sub>4</sub>	58	7.9–8.1

polyphosphates, glassy), tetrasodium pyrophosphate (TSPP), and/or sodium acid pyrophosphate (SAPP). Common muscle foods in which phosphates have been integral include cured pork products (ham, bacon); comminuted meats (frankfurters, bologna); precooked breakfast sausages; delicatessen meats; marinated/injected/tumbled poultry pieces (breasts, wings), and breaded chicken products (tenders, nuggets).

Understanding the importance of food-grade phosphates in the processing of muscle foods requires comprehension of the chemistry of transforming muscle to meat. In life, muscle has a pH of 6.8–7.0.<sup>7</sup> Postmortem glycolysis (rigor mortis) results in a reduction of pH from 5.4 to 5.6.<sup>8</sup> Since the isoelectric point of myosin is pH 5.4, there is no net charge and the water-holding capacity (WHC) of the meat declines rapidly. In the resolution of rigor, pH rises to around 5.8–6.0;<sup>9</sup> adenosine triphosphate (ATP) is depleted and the primary protein is actomyosin, which must be dissociated to actin and myosin for hydration to its native level of approximately 75% moisture. It is estimated that 70% of lean meat volume is composed of the myofibrils and the 50% myosin content has a tremendous ca-

capacity to hold water.<sup>9</sup> The sodium and potassium phosphates exhibit polyelectrolyte behavior, which means that they have the ability to bind to protein and to water. Pyrophosphate is thought to mimic ATP in the live muscle and dissociates actin from myosin. When STPP is added into a muscle system, alkaline phosphatases have been shown to cleave an orthophosphate moiety to yield pyrophosphate.<sup>10,11</sup> Regenstein<sup>12</sup> demonstrated that myosin was solubilized by tetrasodium pyrophosphate > STPP > NaI > NaNO<sub>3</sub> > NaCl > Na<sub>2</sub>SO<sub>4</sub> > sodium citrate. There are restrictions on the total amount of nitrate that can be added to meats; sulfates are permitted only as hog and poultry scald agents; citrates may be used as an anticoagulant, tripe denuding agent, cure color accelerant, or to protect flavor and fresh color; and sodium iodide is not permitted.<sup>13</sup> For centuries, sodium chloride has been used in meats. In addition, in processing, it has been shown that sodium phosphates and NaCl act synergistically, reducing the requirement of NaCl from 3–3.5% to 1.4–1.8%;<sup>14</sup> phosphates compensate for the oxidative effect of NaCl<sup>15</sup> and promote binding of proteins in restructured products. Condensed alkaline phosphates (e.g., TSPP and STPP) and their blends, in

combination with NaCl also raise the pH of meat, which leads to moisture binding approaching that of muscle *in vivo*.<sup>8,14</sup> Phosphates and NaCl also allow the unbound myosin to form a sol (a tacky protein substance) upon mixing and to form a gel upon heating. These actions improve meat binding development (production of delicatessen chicken breast),<sup>16</sup> reduce cook-cool loss to enhance succulence of the cooked product, and restore the WHC of the meat, which began to decrease with the onset of rigor mortis.<sup>17</sup> If SAPP is used in the injection pickle, the pH is less alkaline so that cure color development is accelerated.

The development and stability of an emulsion-like water-fat-protein matrix is key to the production of frankfurters and bologna. The joint action of phosphates and NaCl solubilize myosin so that its hydrophobic tail orients around a fat droplet and the opposite hydrophilic end binds water. Once heat is introduced, the myosin heads orient and undergo oxidation of the sulfhydryl (SH) groups to form the super-thick filamentous structure of the gel between 20 and 50 °C, the first transition temperature. The second stage of gelation takes place between 50 and 70 °C where myosin tails undergo cross-linking and the gel reaches its greatest strength.<sup>16</sup> The medium rare temperature to which consumers cook many meats is 63 °C, while to have a 6.5–7.0 D *Salmonella* reduction process (zero colony-forming units of *Salmonella*), the temperature must reach 70–71.1 °C or an equivalent time-temperature relationship, according to U.S. Department of Agriculture (USDA) Appendix A.<sup>18</sup> (6D is one million to one reduction in CFU/g.) The quantity of cook loss and reduction in succulence at these temperatures is dramatic.<sup>14</sup> Trout and Schmidt<sup>19</sup> showed that the presence of phosphate in beef homogenates increased the thermal transition temperature from 70 to 87 °C, which translates to greater thermal stability of the myosin with reduced moisture loss through cooking. They estimated that at pH 6, without pyrophosphate, moisture loss increased 1% for each degree of temperature rise over 52 °C.<sup>19</sup> Murphy and Marks<sup>20</sup> estimated an increase of 0.2% moisture loss for each degree of temperature rise between 63 and 85 °C. Ready-to-eat seafood products must be cooked to 80 °C for approximately 1.2 s or an equivalent time and temperature relationship for a 6D listericidal process (to reduce the *Listeria*

*monocytogenes* from 1 million CFU/g to 1 CFU/g),<sup>21</sup> but phosphates are not normally used in many of these products (picked crab, crawfish, and lobster).

Phosphates can also have beneficial impacts during distribution and retail operations. For example, phosphates prevent the development of warmed-over flavor in meats,<sup>22</sup> which is the off-flavor that develops from the iron freed from heme during cooking that accelerates lipid oxidation. Phosphates protect color and flavor by binding metals that can catalyze oxidation of lipid and pigment.<sup>9</sup> The sequestering properties of phosphate blends containing STPP and SHMP are very useful when the processing water is hard (100 ppm or more as CaCO<sub>3</sub>) and/or when waters contain appreciable quantities of copper and/or iron. Phosphates help bind water inside the cell during freezing and frozen storage, which, if unchecked, would migrate from the cell and lead to a high concentration of salts that could result in protein denaturation.<sup>23</sup> The use of phosphates also reduces thaw drip loss and purge in chilled storage.<sup>24</sup>

Potassium tripolyphosphate and tetrapotassium pyrophosphate may be used to replace sodium phosphates in meat products in order to reduce total sodium; however, potassium phosphates may result in the bitter bite of potassium at levels exceeding 0.3% of the finished product. Sodium phosphates are limited to 0.5% in the finished meat product (9CFR424.21) by regulation, but are actually self-limiting since, at higher levels, the alkaline salts will saponify lipids leading to a soapy off-flavor. Phosphates are specifically prohibited in ground beef, hamburgers, beef patties, fabricated steak (9CFR319.15), and fresh sausages (9CFR319.140). If phosphates are added to any other meats, their use must be declared on the ingredients statement. Meat and poultry are under the oversight of the USDA and the phosphates may be listed as sodium phosphates.

## Seafood products

Sodium phosphates are used in some seafood products where certain functions are similar to those used for meat products while others are highly specific to seafood biochemistry. For example, as the pH of tuna approaches pH 6.2,<sup>25</sup> there is a tendency for the formation of struvite or magnesium ammonium phosphate, which is a problem because it has

the appearance of glass shards. Struvite may also occur in canned shrimp, crab, cuttlefish, and salmon. Sodium acid pyrophosphate at a level of approximately 0.25% added to the pack<sup>3</sup> will adjust the pH to  $\leq 6.0$ <sup>26</sup> to prevent crystal formation. The blood pigment of crabs is hemocyanin, which contains copper as its oxygen transport metal.<sup>25</sup> Unlike Dungeness crabs that may be butchered and bled before cooking, blue crabs are cooked live. Blue crab may be pasteurized to extend the shelf life up to 1 year if stored at 0–1.7 °C. Since the crabs are not bled, there is an appreciable quantity of copper, which binds with tyrosine to form a blue discoloration to the meat. SAPP (approximately 0.25%) is added to bind the copper to prevent the discoloration.<sup>26</sup>

Crawford<sup>27</sup> developed the process protocol for the application of STPP to *Pandalas jordani* to more efficiently separate the flesh from the shell during mechanical peeling of shrimp. Whole shrimp are dipped in chilled solutions of 3–5% STP for 5 min before steam cooking (90 s) after which the shrimp pass over a series of nips and rollers and are rinsed with water to effect separation of the head, hepatopancreas, and shell from the tail meat. The combination of the alkaline phosphate treatment and heat-facilitated cleavage of the immature collagen that held the exoskeleton to the tail flesh improved (10–12%) recovery of edible flesh for an increase in \$65 million in ex-plant value after the first 8 years of use. There was no increase in phosphorus resulting from the STPP dip before cooking and peeling, and it has been approved as a processing aid in this specific application.

Fish may be processed at sea on factory vessels. For the production of fish sticks, the cod or pollock commonly used will be filleted and frozen into 20-kg blocks. Since these frozen blocks will be sawed into portions using a food-grade band saw, it is critical that there be no voids or gaps between the fish. In order to prevent gaps or voids, the fillets may be passed through a chilled, 10–12% solution of STP for approximately 20 seconds.<sup>28</sup> The conveyor belt flexes to provide even distribution of the chilled STPP solution to the fillet. The STPP solubilizes the surface myofibrillar protein, which imparts tackiness that provides adhesion among fillets to prevent voids. This provides a secondary effect of minimizing oxygen that could lead to oxidation of lipid and pigment.

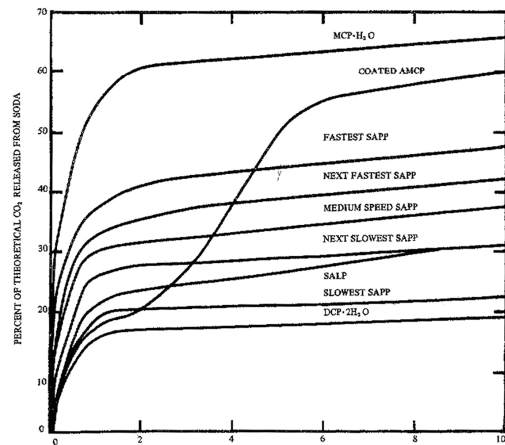
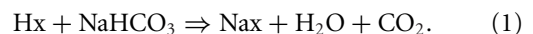


Figure 1. Typical dough rates of reaction.<sup>5</sup>

Surimi is the washed and refined minced flesh of lean fish species. The flesh is typically washed with chilled, potable water in order to remove pigment, lipid, enzymes, and some minerals, and to concentrate the functional myofibrillar protein. Since seafood protein is very labile to chilled and frozen storage, cryoprotectants must be added to maintain functionality of the myofibrillar protein. The composition of the cryoprotectants is often 4% each of sucrose and sorbitol plus 0.3–0.5% of a 1:1 phosphate blend containing STP and TSPP.<sup>29</sup> The blend of washed and refined fish flesh containing the cryoprotectant is frozen in 20-kg blocks for later use to manufacture analogs such as imitation crab.

## Chemical leavening

The major use of phosphates in cereal and grain products is the chemical leavening of cakes, cookies, muffins, doughnuts, crackers, biscuits, battered and breaded foods, pancakes, and waffles. Chemical leavening is an acid– (Hx, i.e., MCP, DCP, SAPP, SALP) base (sodium bicarbonate,  $\text{NaHCO}_3$ ) reaction that produces  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ , and a neutral salt (Nax) as in Eq. (1).<sup>30</sup>



The type of leavening acid hinges upon the dough rate of reaction (DRR or ROR) that is required for a specific product. The DRR is defined as the measure of reactivity ( $\text{CO}_2$  generated) of leavening acid with baking soda during mixing (2–3 min) followed by bench time (5–6 min) of a standard biscuit dough at 27 °C (80.6 °F). Typical DRRs are shown in Figure 1.

In application, deep fried doughnuts require a very rapid DRR while refrigerated dough requires the slowest DRR. DCP appears to give the slowest DRR when compared with other leavening acids; however, it is activated by reverting to MCP when the batter temperature reaches 60 °C (140 °F) and is often used in very dense batters to provide the crown near the end of the baking cycle.

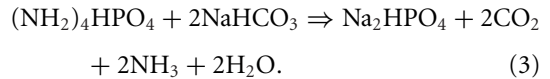
The quantity of leavening acids and bases hinges upon the neutralizing value (NV; the quantity of NaHCO<sub>3</sub> neutralized by 100 parts leavening acid) to allow evolution of all CO<sub>2</sub> and neutralization as shown in Table 2 and Eq. (2).<sup>31</sup>

$$\text{Neutralizing value} = (\text{parts NaHCO}_3 \times 100) / \text{200 parts leavening acid.} \quad (2)$$

Baking powders are available for home and institutional use and large-scale manufacturing. Redried cornstarch is the common diluent used to prevent the acid–base reaction within the container. Large commercial bakers often purchase the leavening acids and bases separately and within tight specifications in order to assure consistent products.

As previously indicated, CO<sub>2</sub> and H<sub>2</sub>O are formed during chemical leavening. Moisture is also added to batters and dough via, for example, milk, eggs, and water. Air is incorporated during mixing. Once heated, CO<sub>2</sub> and air expand and water becomes steam with the combined effect of volume expansion

during the bake, which increases cell or crumb size. A second leavening reaction is mediated by chemical decomposition as shown in Eq. (3).<sup>30</sup>



In this example, DAP and NaHCO<sub>2</sub> react to form DSP, CO<sub>2</sub>, NH<sub>3</sub>, and H<sub>2</sub>O. This type of leavening is suitable only for very low-moisture products such as crispy cookies and crackers because the ammoniacal (NH<sub>3</sub>) odor intensifies with increased moisture content and becomes a flavor defect.

### Dairy applications

Phosphates are used in dairy applications for protein dispersion, to buffer, for ion exchange, acidification, gelation promotion, nutrient supplementation, and sequestrants, and these are described in detail by Ellinger.<sup>5</sup> Many such applications are driven by customer desires. For example, TSPP may be added to chocolate milk to modestly increase viscosity and to maintain dispersion of the cocoa powder. Buttermilk produced by either direct acidification by phosphoric acid or bacterial culture has the casein suspended in acidic whey that, in time, naturally tends to whey-off or form a protein flocculant and an upper layer of whey. TSPP is added to disperse or deflocculate the protein to yield a homogenous product. Further, DSP may be added to milk before drying in order to enhance rehydration and protein dispersion of the nonfat dry milk. TSPP promotes gelation, and DSP and MCP accelerate the setting (gelation of casein) of milk protein in instant puddings and cheesecakes. In shelf-stable milk, titratable SH groups decrease during storage and gelation occurs. Added SHMP will bond with calcium to form a covalent linkage with a stable calcium caseinate–calcium orthophosphate complex to retard gelation. DKP is added into formulations of coffee whiteners to inhibit feathering when the creamer is added to the acidic coffee medium.

One of the major uses of phosphates in dairy products is in processed cheese to modify properties such as smooth melt (to prevent the butter oil from separating from the protein), easy slice (single, individually wrapped slices), spreadability, and desired viscosity. Two more recently developed uses of food-grade phosphates include the double and triple calcium–fortified processed cheeses (TCP) and the

**Table 2.** Properties of selected commercially available phosphate leavening acids<sup>31</sup>

Phosphate leavening acid	Neutralizing value	Two-minute mix stage	Leavening gas released (%)	
			Five- to six-minute bench action	During baking
SAPP 22	70	22	11	67
SAPP 28	70	28	8	64
SAPP 40	70	40	8	52
MCP-1	80	60	0	40
MCP-0	83	15	35	50
DCP-2	33	0	0	100
CAPP	67	44	6	50
SALP-4	100	22	9	69
SALP-A	100	21	4	75

**Table 3.** Selected nonhuman food applications, indirect food contact, and processing-aid uses of food-grade phosphates in food processing

Nonhuman food use	Indirect food contact	Processing aids
Cosmetics (Na)	Adhesives and coatings (Na, PWA)	Carcass washes (Na)
Animal feed (Na, PWA, Ca)	Sanitizers (Na, PWA)	Scald/denuding poultry and hogs (Na)
Mouthwash (Na)	Food contact polymers (Na)	Rendering of lard (Na, Ca)
Anticoagulant (Na)	Packaging materials (Na, Ca)	French fry processing (Na)
Pet food (Na, PWA)	Plastic wrap extrusion (Na)	Mechanical peeling of Pacific Northwest shrimp ( <i>Pandalas jordani</i> ), (Na)
Dentifrice (Na, Ca, K)	Antiwear agent in lubricants (Ca)	Egg cleaning (Na)
Metal finishing (Na, PWA)	Lubricating/can manufacturing (PWA)	Hydration-limiting agent for chewing gum (Ca)
Yeast and bacterial nutrient (PWA, K, A)	Styrofoam polymerization (Ca)	Cane sugar refining (PWA)
Pet food supplement (Ca)	Scale removal in dairy and beer facilities (PWA)	Oil degumming (PWA)
Photocopier toner (Ca)		
Tobacco products to control burn (A)		

Na, sodium phosphates; PWA, purified wet acid; Ca, calcium phosphates; K, potassium phosphates; A, ammonium phosphates.

ultra high temperature–stable mozzarellas (SHMP) used in stuffed-crust pizzas.

Natural cheese is a weak emulsion.<sup>32</sup> The process of aging involves proteolysis and some lipolysis to develop flavor and texture of the cheese resulting in, for example, the distinctive flavor and eyes of Swiss cheese; however, this process further weakens the emulsion. Upon heating, the weakened emulsion separates into two phases, coagulated protein and the weeping off of butter oil. The addition of phosphate salts, often termed, although a misnomer, emulsifying salts, modifies the protein rather than forming a true emulsion and these are more accurately termed melting salts.<sup>32</sup> Good melting salts (1) have polyvalent anions; (2) form alkaline solutions (raise the cheese pH from 5.4–5.6 to 5.8–6.0); (3) are calcium-complexing agents; (4) have ion exchange capacity; (5) disperse proteins; (6) have low molecular weight for fast reaction; and (7) are neutral in flavor.<sup>33</sup> In the production of process cheese, there are three fundamental physicochemical reactions. There is a chemical ion exchange of the sodium from DSP with the calcium of calcium caseinate to form

DCP bridges, and the calcium caseinate becomes sodium caseinate. Heating causes enhanced surface activity and molecular interaction of constituents. The mechanical action or stirring within a steam-jacketed vessel allows for the redistribution of cheese constituents and added ingredients. The sodium caseinate forms a film around the fat droplets, which then imparts the desired characteristics.

### Fruit and vegetable applications

Potatoes will discolor by three mechanisms: (1) browning occurs via polyphenoloxidase, which is initiated when the potato surface is exposed to air; (2) Maillard browning is the result of amino acid and reducing sugar interaction when heated; and (3) blackening of the cut potato surface is the oxidation of *o*-diphenolic compounds in the presence of iron.<sup>34</sup> Commercially prepared French fries are par-cooked and frozen and, as such, are particularly prone to blackening after the heat treatment. Dilute solutions (0.9–1.2%) of SAPP at 140–160 °F are sprayed on the potatoes in order to sequester the iron and prevent the after-cook blackening.<sup>35</sup>

## Beverages

Phosphoric acid is the acidulant and a flavorant used in colas and root beer at levels of 0.05% and 0.01%, respectively. Tricalcium phosphate (0.1–0.2%) was the preferred calcium source in fortified orange juice and it also modestly increased viscosity due to the interaction of calcium and pectic acid. The use of TCP has now been offset by CaOH, calcium citrate, and calcium acetate. Sodium and potassium orthophosphates are commonly added to isotonic beverages for electrolyte replacement. In nutritional beverages (including infant formulas) intended as either supplements or meal replacements, calcium orthophosphates may be used in addition to the sodium and potassium orthophosphates. In dry beverage mixes, MCP may be used as a nonhygroscopic acidulant and partial replacement for citric acid while TCP may function as an anticaking and clouding agent. In noncarbonated beverages, such as fruit drinks and canned teas, SHMP may be added to sequester minerals essential to acid-tolerant yeasts.

## Nonfood uses of food-grade phosphates

There have been concerns that the consumption of the food-grade phosphates is increasing. When based upon production data, it is important to note that many uses require food-grade ingredients, and some key applications are outlined in Table 3.

## Conflicts of interest

The author declares no conflicts of interest.

## References

- Orris, G.J. & C.B. Chernoff. 2002. *Data Set of World Phosphate Mines, Deposits and Occurrences—Part B Location and Mineral Economic Data*. Washington DC: U.S. Geological Survey, Department of the Interior.
- Van Wazer, J. 1958. *Phosphorus and Its Compounds*. Vol. I New York: Wiley Interscience.
- Lampila, L.E. & J.P. Godber. 2001. "Food phosphates." In *Food Additives*. A.L. Branen, P.M. Davidson, S. Salminen & J.H. Thorngate, III, Eds.: 809–896. New York, NY: Marcel Dekker.
- Molins, R. 1990. *Phosphates in Food*. Boca Raton, FL: CRC Press.
- Ellinger, R.H. 1972. *Phosphates as Food Ingredients*. Cleveland, OH: CRC Press.
- Demian, J.M. & P. Melnychyn. 1971. *Phosphates in Food Processing*. Westport, CT: The AVI Publishing.
- Forrest, J.C., E.D. Aberle, H.B. Hedrick, et al. 1975. *Principles of Meat Science*. San Francisco, CA: W.H. Freeman.
- Hamm, R. 1960. Biochemistry of meat hydration. *Adv. Food Res.* **10**: 355.
- Hamm, R. 1986. "Functional properties of the myofibrillar system and their measurements." In *Muscle as Food*. P.J. Bechtel, Ed.: 135–199. Orlando, FL: Academic Press.
- Sherman, P. 1961. The water-binding capacity of fresh pork. III. The influence of cooking temperature on the water binding of lean pork. *Food Technol.* **15**: 90.
- Bendall, J.R. 1954. The swelling effect of polyphosphates on lean meat. *J. Sci. Food Agr.* **5**: 468.
- Regenstein, J.M. 1984. Protein-water interactions in muscle foods. *Reciproc. Meat Conf. Proc.* **37**: 44.
- Code of Federal Regulations. 2013. Accessed February 14, 2013. [www.ecfr.gov](http://www.ecfr.gov).
- Shults, G.W., D.R. Russell & E. Wierbicki. 1972. Effect of condensed phosphates on pH, swelling and water-holding capacity of beef. *J. Food Sci.* **37**: 860–864.
- Matlock, R.G., R.N. Terrell, J.W. Savell, et al. 1984. Factors affecting properties of raw-frozen pork sausage patties made with various NaCl/phosphate combinations. *J. Food Sci.* **49**: 1363–1366.
- Acton, J.C. & R.L. Dick. 1984. Protein-protein interaction in processed meats. *Reciproc. Meat Conf. Proc.* **37**: 36.
- Hamm, R. & R. Grau. 1955. The effect of phosphates on the bound water of meat. *Dtsch. Lebensmitt. Rdsch.* **51**: 106.
- USDA. 1999. *Appendix A – Compliance Guidelines for Meeting Lethality Performance Standards for Certain Meat and Poultry Products*. Washington DC: Food Safety and Inspection Service. U.S. Department of Agriculture.
- Trout, G.S. & G.R. Schmidt. 1987. The effect of cooking temperature on the functional properties of beef proteins: the role of ionic strength, pH, and pyrophosphate. *Meat Sci.* **20**: 129.
- Murphy, R.Y. & B.P. Marks. 2000. Effect of meat temperature on proteins, texture, and cook loss for ground chicken breast. *Poultry Sci.* **79**: 99.
- FDA. 2011. *Fish and Fishery Products Hazards Guide*. Washington DC: Food and Drug Administration, Center for Food Safety and Applied Nutrition.
- Trout, G. & S. Dale. 1990. Prevention of warmed-over flavor in cooked beef: effect of phosphate type, phosphate concentration, a lemon juice/phosphate blend, and beef extract. *J. Agric. Food Chem.* **38**: 665.
- Matsumoto, J.J. 1980. "Chemical deterioration of muscle proteins during frozen storage." In *Chemical Deterioration of Proteins*. J.R. Whitaker, Ed.: 95–124. Washington DC: American Chemical Society.
- Boyd, J.W. & B.A. Southcott. 1965. Effect of polyphosphates and other salts on drip loss and oxidative rancidity of frozen fish. *J. Fish. Board Can.* **22**: 53–67.
- Finch, R. & G. Courtney. 1976. "The tuna industry." In *Industrial Fishery Technology*. M.E. Stansby, Ed.: 91–109. Huntington, NY: Robert E. Krieger Publishing.
- Otsuka, S. & H. Osada. 1970. Electrical Processing of Marine Products. U.S. Patent 3, 547, 657. December 15.
- Crawford, D.L. 1980. Meat yield and shell removal functions of shrimp processing. Oregon State University Extension Marine Advisory Program Special Report 597.
- Crawford, D.L., inventor; Benckiser-Knapsack, assignee. 1984. Composition for treating fish to increase fish yield. U.S. Patent 4, 517, 208. January 13.

29. Matsumoto, J.J. 1978. Minced fish technology and its potential for developing countries. In *Proceedings on Fish Utilization Technology and Marketing*, 18, 267. Bangkok: Indo-Pacific Fishery Commission.
30. Brose, E., G. Becker & W. Bouchain. 1996. *Chemical Leavening Agents*. Budenheim, Germany: Chemische Fabrik Budenheim Rudolf A. Oetker.
31. Pyler, E.J. 1988. *Baking Science & Technology*. Merriam, Kansas: Soslund Publishing Company.
32. Berger, W., H. Klostermeyer, K. Merkenich & G. Uhlmann. 1993. *Processed Cheese Manufacture: A Joha Guide*. Ladenburg, Germany: BK Ladenburg.
33. Zehren, V.L. & D.D. Nusbaum. 1992. *Process Cheese*. Green Bay, WI: Schreiber Foods.
34. Siciliano, J., E.G. Heisler & W.L. Porter. 1969. Relation of potato size to after-cooking tendency. *Am. Potato J.* **46**: 91.
35. Smith, O. & C.O. Davis. 1962. Potato quality XIII. Preventing after-cooking discoloration in oil blanched French fries. *Am. Potato J.* **39**: 45–56.