Review Article

Open Access

Food-grade phosphates in the Seafood Industry: technological functions, quality, safety, and integrity implications

Abstract

This review consolidates and systematizes current knowledge on the use of food–grade phosphates in the seafood industry. Information on their technological roles, mechanisms of action, and regulatory aspects remains widely scattered across scientific papers, book chapters, and technical reports. Therefore, this review provides a comprehensive and reliable reference for researchers, quality managers, inspectors, regulatory authorities, and industry professionals. The review discusses the origin, classification, physicochemical properties, and interactions of phosphates with muscle proteins, emphasizing their technological functions throughout seafood processing. Scientific evidence demonstrates that phosphate additives effectively improve water–holding capacity, yield, texture, and shelf life. However, improper or excessive use can cause sensory defects, loss of consumer confidence, and economic fraud. Further sections address analytical detection, toxicological considerations, and regulatory frameworks governing their use. The challenges in establishing universal legal limits are highlighted, given the natural variability of phosphorus content in seafood, analytical interferences, and the absence of harmonized international standards. Importantly, exceeding national phosphorus or sodium limits may not necessarily represent a health hazard if total dietary intake remains within tolerable levels. Additionally, environmental and sustainability implications related to phosphate production and use should not be overlooked. Overall, the responsible and transparent use of food-grade phosphates, supported by robust analytical methods, harmonized legislation, and continued scientific research, is necessary to ensure product quality, consumer safety, and integrity within the seafood sector.

Keywords: seafood, food additives, phosphorous, phosphate, water retention, economic losses

Volume 13 Issue 2 - 2025

Alex Augusto Gonçalves, Raimunda Thyciana Vasconcelos Fernandes

Laboratory of Seafood Technology and Quality Control (LAPESC), Department of Animal Science, Center for Agricultural Sciences, Federal Rural University of the Semi–Arid, Brazil

Correspondence: Dr. Alex Augusto Gonçalves, Federal Rural University of the Semi–Arid, R. Francisco Mota, 572 – Pres. Costa e Silva, 59625–900, Mossoró, RN, Brazil, Tel + 55 84 33178300 r 1419; +55 61 99173–8910

Received: November 27, 2025 | **Published:** December 23, 2025

Introduction

Seafood plays a central role in food and nutritional security, as it makes up the human diet worldwide, contributing several essential nutrients (proteins, vitamins, minerals, and fatty acids), which are important for human health.[1–4] Notably, the mineral composition of seafood varies significantly due to seasonal and biological factors, including species, size, type of muscle (white *vs*. dark), age, sex, and sexual maturity.[1,2,5,6] Other influencing factors include the capture area, environmental conditions, and processing method.[3,6,7] Within an individual organism, the concentrations may vary from tissue to tissue and with age.[8,9] The mineral content of the same species can vary between studies conducted by different authors.[4,5] Therefore, it is not advisable to compare values obtained from various studies because the aquatic species may have lived under different conditions at the time of capture.[1]

In addition, minerals, as inorganic elements widely found in nature, play a diverse range of metabolic roles within the body, encompassing activation, regulation, transmission, and control.[3,5–7] In the specific context of phosphorus, this mineral plays a vital role in various biological processes. It is essential in the intermediary metabolism of proteins (as phosphoproteins), lipids, and carbohydrates (forming part of glycogen). Phosphorus is integral to the structure of nucleic acids and actively participates in the cellular secondary messenger system and transduction mechanism.[1,8,10]

This involvement triggers hormonal responses, stimulating the synthesis and secretion processes of specific cells and organs essential to reproductive activity. Additionally, phosphorus contributes to the composition of lipoproteins, the primary carriers of fatty acids in the body, aids in the proper functioning of nerves, and plays a key role in the formation of bone structure.[1,2,8,9,11]

In the process of energy transfer, phosphorus plays a direct role in the creation of adenosine triphosphate (ATP), adenosine diphosphate (ADP), and adenosine monophosphate (AMP) molecules.[10,12–15] These nucleotides are present in tissues and are necessary for both molecular metabolism and the regulation of energy absorption and release. It's noteworthy that ATP serves as the primary carrier of energy in seafood, and most of the energy required for metabolic processes in these organisms is derived from the hydrolysis reactions of these molecules. The breakdown of an ATP molecule produces ADP, phosphate, and energy. However, during seafood post–mortem, ATP undergoes natural degradation, leading to the buildup of phosphorus in muscle tissue.[13–16]

In this context, the presence of natural phosphorus, along with other natural sources of phosphorus, has sparked debate, as it can erroneously indicate an incorrect outcome for untreated (raw) seafood compared to seafood treated with the food–grade additive phosphate.[17] It's important to remember that phosphates, including polyphosphates, are inherent in all forms of life and, consequently, are present in nearly all food items. Naturally occurring phosphates encompass single phosphate groups (orthophosphates) as well as various phosphate chain lengths, including 2 phosphate groups (pyrophosphates), 3 phosphate groups (tripolyphosphate), and chains with 4 or more phosphate groups (polyphosphates).[18–20]

Nevertheless, note that measuring phosphate levels in seafood is not a straightforward task. It is necessary to differentiate between naturally occurring levels, which are not precisely defined in scientific literature due to their variability, and levels that are intentionally added through food–grade phosphate additives.[18,21–24] As previously noted, protein–rich foods, such as seafood, contain phosphorus compounds, including nucleotides, phospholipids, and naturally occurring orthophosphates.[12–16] Consequently, relying solely on the quantification of phosphorus (i.e., phosphate) is insufficient for confirming the presence of added phosphates, given the existence of naturally occurring orthophosphates and other phosphorus compounds in muscle tissue.

Moreover, the biological variation in total phosphorus content (0.036–1.57%) among individuals and the broad range (0.11–4.8%) of natural orthophosphate (or phosphate) contents[19,25] pose challenges in detecting added phosphates through isolated quantitative analysis.[16,21] However, the inclusion of additional protein–rich components, such as milk extracts, oils, and proteins, in seafood products may influence the findings. This aligns with the research conducted by Watanabe et al.[26] which highlighted that processed foods demonstrate higher levels of protein and phosphate content compared to fresh foods, as well as a greater phosphate–to–protein ratio.

Seafood and phosphates

Seafood, or *aquafood* in a broader sense (including marine, freshwater, and brackish food), encompasses all aquatic organisms intended for human consumption, such as fish, mollusks, crustaceans, amphibians, chelonians, mammals, echinoderms, macroalgae, and more. These products enjoy global popularity due to their high nutritional quality, resulting in significant consumer demand. Moreover, as product costs increase, consumers expect seafood products to maintain excellent quality with minimal loss of weight and nutrients.[27–30]

Nevertheless, right after being caught, the edible portion of seafood undergoes a series of intricate changes involving enzymatic, biochemical, and microbiological processes.[10,17,27,30] These transformations occur on both the surface and inside the edible portion, leading to a reduction in quality and a potential decrease of up to 80% in water retention capacity.[17,31–33] It should be highlighted that a significant portion of the edible portion of seafood is water. This significantly affects its sensory qualities, overall quality, and shelf life in terms of weight and volume.[22,34,35]

Recognizing these issues, commercial practices globally have incorporated measures to regulate, add, and maintain moisture in seafood throughout the stages of capture, processing, distribution, storage, and preparation. For instance, the use of the food–grade additive “phosphate” has been employed for many years to treat seafood, ensuring its stability and quality.[16,18,20,28,29,33–41]

Furthermore, inorganic phosphate additives are globally recognized as multifunctional additives, allowing for the use of multiple additives in a product or a larger addition of one for various functions.[18,20,24] This contributes to phosphate intake while also serving as an alternative to ensuring the quality of seafood and its derivatives.[18,35,37,38]

In this context, with ongoing technological advancements and industries continually innovating with new products, this food additive needs to perform all its functions effectively, ensuring the production of stable and safe products. From this perspective, numerous patents related to the use of polyphosphates in seafood are available; some of these are highlighted in Table 1 (United States Patent and Trademark Office – USPTO) for their role in preventing drip loss and retaining the natural organoleptic quality of seafood. The first patented study using phosphates to ensure the quality of seafood was in 1939 in the USA, utilizing dibasic phosphates to reduce the formation of a blue color in processed crab meat.

Table 1 History of US Patents* associated with phosphate production and its application in seafood.

Patent number	Patented date	Description
US-1927123-A	Sept. 19, 1933	Process of treating crustaceans to prevent coloration therein
US-2174614-A	Oct. 03, 1939	Method of producing polyphosphates and polyphosphates mixtures.
US-2488184-A	Nov. 15, 1949	Processing of shrimp
US-2555236-A	5-May-51	Process of canning fish and shellfish and resultant product
US-2735777-A	Feb. 21, 1956	Process for the improvement of taste digestibility, and stability of fish meat
US-2758930-A	Aug. 14, 1956	Method of preserving shrimp
US-2986449-A	30-May-61	Process for the production of alkali metal polyphosphates
US-3036923-A	29-May-62	Preservation of fish
US-3449068-A	Jun. 10, 1969	Process for the manufacture of polyphosphates
US-3620767-A	Nov. 16, 1971	Bonito processing
US-3705040-A	Dec. 05, 1972	Process of extracting meat from crustaceans particularly shrimp
US-4075357-A	Feb. 21, 1978	Intermediate moisture meats
US-4221819-A	Sept. 09, 1980	Water and color retention treatment for frozen processed shrimp
US-4293578-A	Oct. 06, 1981	Method of treating fresh shrimp to reduce moisture and nutrient loss
US-4394396-A	Jul. 19, 1983	Shrimp processing
US-4431679-A	Feb. 14, 1984	Composition for treating fish fillet to increase yield and shelf life
US-4670277-A	Jun. 02, 1987	Increased shelf-life for refrigerated fish
US-4937092A	Jun. 26, 1990	Increased shelf life for refrigerated fish

Table 1 Continued....

US-5262186-A	Nov. 16, 1993	Process for treating fish and shellfish to control bacterial contamination/growth
US-5436025-A	Jul. 25, 1995	Cryoprotected surimi product
US-6001396-A	Dec. 14, 1999	Method and solution for improving frozen seafood quality
US-6274188-B1	Aug. 14, 2001	Method for steam-cooking shrimp at reduced temperatures to decrease yield loss
US-20150196040-A1	Jul. 16, 2015	Process to produce safe pasteurized shrimp and other shellfish of high sensory quality and extended refrigerated shelf-life

*USPTO - United States Patent and Trademark Office - Patent Public Search: An official website of the United States government (https://ppubs.uspto.gov/).

Subsequently, new patents on the production of food–grade polyphosphates and blends began to appear. In 1949, a new study on the use of phosphates in seafood, specifically shrimp (2% disodium phosphate), was patented, showing that this additive prevented liquid loss during post–cooking. Following this, additional patents covering other species were approved, generating interest among researchers and the industry. Subsequently, numerous studies have been conducted by research institutions in Iceland, Norway, Portugal, China, Canada, the United States, and Brazil, aiming to explore the various applications of this additive, especially within the seafood industry (see section "*Specific applications of phosphates in seafood*").

It is highlighted, however, that the application of phosphates in certain sectors of the seafood industry has undergone thorough examination by governmental bodies in various nations. Excessive moisture absorption resulting from improper use has raised concerns about potential economic fraud. The quality and shelf life of the product can be negatively impacted by excessive water loss, which can in turn affect consumer acceptance. Presently, countries with a rich tradition of seafood production and consumption, including Argentina, Uruguay, Chile, Peru, Ecuador, Mexico, the United States, Canada, Portugal, Spain, Iceland, Norway, China, Japan, and many others, conscientiously employ the food–grade additive "phosphate" within allowable limits, except Brazil (not allowed until July 2025),[42] and the USA,[43] which consider phosphate GRAS – *Generally Recognized as Safe* (a status that limits the amount added to foods to be determined by a guide known as GMP – Good Manufacturing Practice), which leaves the amount added to a food to the discretion of the manufacturer to enhance seafood quality and meet consumer satisfaction.

This usage is in accordance with the respective legislation based on the Codex Alimentarius. However, when used prudently, phosphates preserve the natural juices by rehydrating lost water during the post–mortem period, resulting in softer and juicier products, in addition to not influencing flavor. In this regard, having specific and approved legislation for the application of phosphates in seafood is essential. This not only enhances the quality of the products provided to consumers but also reduces economic losses in processing (such as minimizing losses in production lines) and contributes to the overall fight against fraud.[18,32,33,35,38,40,44–46]

Classification and nomenclature of phosphates

Phosphates are derived from the refinement of naturally occurring calcium phosphates found in mineral rocks. Through the total or partial neutralization of phosphoric acid with alkali metal ions (such as sodium, potassium, or calcium), two primary classes of phosphates are created: orthophosphates and pyrophosphates. The fundamental structures for phosphate salts are orthophosphoric acids. Salts formed by the reaction with a base, such as sodium hydroxide, are consequently known as orthophosphates. Heating orthophosphates under controlled pH conditions leads to the formation of pyrophosphates, also known as diphosphates. Furthermore, polymerization occurs under controlled conditions with higher temperatures, resulting in the production of tripolyphosphates and components with higher molecular weights.[18,34,47]

Table 2 subsequently provides detailed information on the phosphates used in various food products. It presents their functional class, toxicological references, acceptable daily intake, and maximum tolerable daily intake.

Physical, chemical properties and functions

Water is the predominant component in seafood, playing an important role in various biochemical, microbiological, and physical reactions. These processes significantly impact on the sensory, nutritional, and functional properties during processing and storage.[31,48,49] According to Chan et al.[48] water–holding properties (WHP) embrace drip loss (DL) and water holding capacity (WHC), two key indicators of freshness, considering the affinity between seafood muscle and water. Considering the importance of water in foods, and especially in seafood, moisture retention is typically linked to the WHC and pH of proteins.[50,51]

It is essential to emphasize that the myofibrillar proteins in seafood undergo rapid denaturation at refrigeration temperatures (5°C) after capture, resulting in a potential loss of water retention capacity within 5 days.[31] Failing to safeguard these delicate proteins not only poses challenges in determining the appropriate net weight but also carries negative economic consequences for seafood processors.[18,46,52–54]

The nutritional value and sensory quality of the product decline due to additional losses of inherent moisture, vitamins, and minerals that occur during the thawing and cooking processes. This is noticeable through the development of a dry, hard–textured product. Furthermore, drip losses create protein suspensions that encourage bacterial growth, consequently diminishing the product's shelf life.[52,53,55,56]

It's important to highlight that phosphates possess a distinctive capability to replenish the WHC of proteins, thereby preserving the natural moisture of the product and reducing drip losses during frozen storage, thawing, and cooking processes.[29,52,54] Moreover, with the extension of the phosphate chain, the bacteriostatic effects intensify. Consequently, when consuming phosphate–treated seafood, consumers enjoy juicier products with enhanced texture, while the expected nutritional value is retained.[18,32,38]

Every type of seafood contains actomyosin, a protein responsible for retaining water in the product. In living muscle, the natural phosphate in the form of ATP regulates the structure of actomyosin, facilitating the natural binding or retention of water. However, after death, biochemical reactions decrease the ATP levels, converting them into lactic acid and consequently reducing the muscle's pH (creating an acidic condition).[12,13,15]

At this point, the proteins bind together, resulting in the loss of the meat's water retention ability, and the edible portion transforms into a dry product with a fibrous texture (Figure 1). The phosphates increase the pH level to approximately 6.4. If the final pH level of the product is very high, its shelf life will decrease, and it will exhibit failures such as sliminess, translucency, and fat decomposition. Due to the increased water–holding capacity of cooked meat proteins, the following improvements are generally observed: increased yield (8–10%), improved flavor retention, and improved texture.[38,44,45]

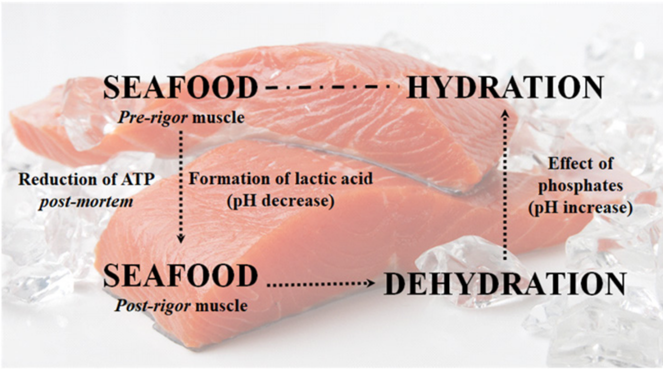


Figure 1 Effects of phosphate on muscle biochemistry (refrigeration temperature ~5°C).

Polyphosphates play a key role in regulating ATP levels. ATP acts as a carrier of chemical energy within cells for metabolism. Unlike other energy sources, ATP cannot be stored; instead, it undergoes continuous recycling through breakdown and synthesis processes within organisms.[57] Incorporating phosphates into seafood yields multifunctional properties. One notable property is its ability to interact with ATP and restore proteins' water retention capacity. This impact on water molecule binding is attributed to a specific polyanionic or charge–altering effect on muscle proteins. This effect is specifically achieved by a group of specialized phosphates known as "diphosphates", which induce proteins to attract water molecules.[18,38]

Additionally, the moderate increase in pH (resulting in a less acidic condition) due to phosphate use is a significant, though not the sole, factor contributing to water retention. In this sense, when muscle pH is close to 5.4 (which refers to the isoelectric point of the protein), seafood proteins have a reduced water retention capacity,[15,33,40,41,45,46] with phosphates being able to raise the pH to an ideal level of approximately 6.4. However, if the final pH level of the product is too high, it reduces the shelf life and causes issues like translucency, a soapy appearance, and fat decomposition. Optimal results are achieved when using phosphates with a pH ranging from 7 to 10. The enhanced WHC of the protein in cooked meat typically results in various improvements, including an increased yield (8 to 10%), better retention of flavor, and improved texture.[33,40,41]

An additional advantageous role of phosphates lies in their capacity to sequester and chelate metal cations, including Ca^{2+}, Mg^{2+}, Fe^{2+}, and Fe^{3+}, forming chelates that facilitate their elimination. This chelation of ions helps inhibit the onset of oxidative rancidity and stabilize the color, particularly as the chelation of Ca^{2+} and Mg^{2+} influences water retention capacity.[18,34,38,58,59] Phosphates also play a role in preventing the formation of struvite crystals that can occur during the processing of canned products. For example, phosphates such as sodium acid pyrophosphate (SAPP) bind to magnesium ions, which prevents the formation of these crystals.[18,35,38,58]

General applications of phosphates

For many years, polyphosphates have been used in processing meat, poultry, and aquafood to improve WHP. These compounds modify the meat pH and ionic strength around the protein, causing the protein to unfold and expose areas that increase its ability to absorb water.[48,49] This results in less water loss during cooking or thawing.[18,34,36,37,59,60] The improved WHP leads to benefits such as decreased moisture loss during cooking, increased yield after cooking, reduced moisture loss during thawing, improved softness and texture, better retention of flavor and aroma by minimizing the loss of natural juices and flavors during processing, and improved binding between muscle pieces.[18,20,34,37] Typically, in the processing plant, four primary types of phosphates are utilized alone or in combinations[18,34,35–39,60] as detailed as follows:

i) Sodium Tripolyphosphate (STPP) is a multifunctional phosphate for all applications, i.e., meat, poultry, and seafood. Its use is more economical, and it performs most of the functions of other, more expensive mixtures. It is suitable for use in brines (hams, chicken fillets, and seafood), in solutions (marinades, fish, and shrimp peeling), for dry addition (sausages, mortadella, etc., and for tumbling).

ii) Sodium and Potassium Tripolyphosphate (SKTPP) is a reduced sodium polyphosphate, combining the functionality benefits of phosphates with high solubility and ease of use; in addition, SKTPP does not result in the tastelessness usually associated with potassium.

iii) Tetrasodium Pyrophosphate (TSPP) is an alkaline phosphate used when maximum protein solubilization is required; however, its use is limited by its low solubility. Therefore, it is used in combination with other more soluble phosphates or in dry applications; and

iv) Sodium Acid Pyrophosphate (SAPP) pure or in blends (SHMP or SAPP and/or TSPP + NaCl) is an acid phosphate often used as a dry ingredient to stabilize emulsions. Favors color development and improve flavor and texture in sausages and other emulsified products.

Thórarinsdóttir et al.[61] demonstrated that the efficacy of phosphates in enhancing water retention properties in meat products was contingent on the specific type and quantity of phosphate used, along with the nature of the product processed with the addition of phosphate. Phosphates are commonly administered through methods such as dipping, spraying, injecting, or tumbling at varying concentrations. Dry addition is also employed in ground (restructured/embedded) meat systems. Among these methods, vacuum tumbling is considered the most effective way to apply phosphate. However, it's important to note that excessive tumbling can cause the protein to be extracted before the phosphate solution is absorbed.[25,61]

The typical concentrations of phosphates commonly used in the food industry through processing (weight/volume) are outlined as follows: ice production (3% w/v), washing (2–6% w/v), soaking/immersion (2–6% w/v), spraying (5–10% w/v), tumbling (2–6% w/v), injection (5–8% w/v), glazing (5% w/v), and dry addition (0.3–0.5% w/w).[18,34,35,36,38]

To achieve optimal protein activation, phosphates are applied in solutions ranging from 2% to 10%, resulting in approximately 0.5% residual phosphate in the final product. Another method involves applying phosphates using ice prepared with phosphate and water. The specific concentrations and treatment duration depend primarily on the seafood species (considering fat content) and types of cuts. The treatment is most effective when performed shortly after capture and should precede any heat treatment. Combinations of various phosphates and other approved food ingredients in blends can potentially influence the pH and/or antimicrobial properties of the mixture (blend).[18,33,34,40,41,46] While it is not common in the seafood industry, using phosphates in the glazing process can prevent product dehydration during storage. However, they do not significantly reduce thawing loss. In this context, the advantage of applying phosphate during the glazing process lies in the improved handling of frozen products, making them more resistant to breakage and resulting in substantial cost savings.[18,32,34,35,37,38,40,41,44–46]

Specific applications of phosphates in seafood

Before discussing the various applications of phosphates in seafood, note that heat treatment can reduce product yield, which may have adverse economic implications for the industry. However, some studies have demonstrated the advantageous effects of using phosphate additives in mitigating these losses.[35,38–41,44–46,55,56,62–65] In this regard, Table 3 summarizes the findings from the literature regarding the utilization of phosphate in seafood processing.

Shrimp that are steamed and then passed through flexible steel rollers are usually treated with an STPP solution. In this process, the meat is separated from the shell, weakened by Ca^{2+} chelation.[36] Crawford[64] developed a method for applying 3–5% STPP (5 min.) to *Pandalus jordani* shrimp, followed by a 90–second steaming process, which enhances the mechanical separation of meat from the shell. Subsequently, the shrimp undergoes mechanical peeling and is washed with water to separate the head, hepatopancreas, and tail meat rind. Another method of mechanically removing shrimp shells involves using an STPP solution ranging from 1% to 6%, though concentrations sometimes reach 8–10%. This approach increases shrimp meat recovery by 20 to 30%, calculated based on the initial weight.[36]

Since shrimp are highly perishable, they must be stored at low temperatures to maintain quality and safety over time. All phosphate treatments should be performed at temperatures below 4°C, or between 0°C and 2°C for prolonged exposure. Therefore, low temperatures must be sustained throughout the exposure period, and the chosen phosphates must exhibit increased solubility at low temperatures and retain their solubility at these levels. The processing of shrimp varies depending on the species and consumer demand. [38,40,41,44,45]

Properly applying phosphates in shrimp processing improves product yield and provides sensory benefits for consumers.[40] In the case of peeled or peeled and deveined/gutted shrimp treated with 2–4% phosphate for 20–120 minutes (at 4°C), there is a 5 to 8% increase in acceptability compared to untreated shrimp. Meanwhile, value–added peeled shrimp (butterfly cut) treated with 2–4% phosphate for 10–25 minutes (< 4°C) exhibit an 8–10% increase in acceptability.[18,32,36,40,41,45] The findings from Gonçalves and Ribeiro[44] suggest that immersing peeled shrimp in a 5% STPP and 5% phosphate blend solution can effectively mitigate losses associated with thawing and cooking. It is evident that judicious and compliant use, within the limits set by international regulations, not only prevents economic fraud related to weight gain but also facilitates water retention post–thawing and after heat treatment (cooking), as illustrated in Figure 2.

Furthermore, sensory analysis demonstrated that shrimp treated with phosphate maintain sensory attributes, enhancing overall preference and acceptability. From this perspective, according to Ying et al.,[66] when evaluating the quality of white leg shrimp pre–soaked with phosphates during frozen storage, the physicochemical analysis indicated significant improvements in the WHC, springiness, chewiness, and thermal stability of STPP and STMP pre–soaked samples when compared to untreated samples.

In turn, frozen storage of lobster meat can result in undesirable quality changes that decrease consumer acceptance of these products. In this sense, the use of cryoprotective agents that contain phosphates, including a blend (STPP + NaCl), in soaking for 2 minutes, promotes an increase in the sensory quality of frozen lobster meat.[42]

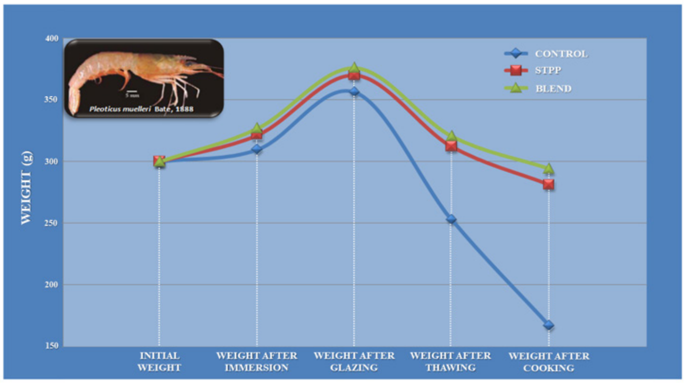


Figure 2 Weight changes after immersion of peeled shrimp (5% STPP, 5% phosphates - Blend, and water as a Control), and after thawing and cooking processes (Adapted[32]).

In their study, Gonçalves et al.[45] showed that phosphate mixture solutions (blend) resulted in a higher yield compared to the use of phosphate alone (STPP) across four distinct seafood species (fishes – *Genypterus brasiliensis* and *Prionotus punctatus*; shrimp – *Pleoticus muelleri*; and mussel – *Perna perna*). This could be attributed to the composition of the phosphate mixture, which enhances the additive's effectiveness in boosting water–holding capacity (WHC) and, consequently, the overall yield.[38,44] Longer contact times and higher phosphate concentrations were associated with lower weight reduction in shrimp.

The best results for fish fillets are achieved by immersing or washing them in a solution of 2-6% phosphate until the residual phosphate content is about 0.5%. While some species require less than 1 minute of treatment to reach this level, others may not surpass it even with prolonged exposure. Phosphate solutions prove highly effective and controllable when in direct contact with fish meat rather than the whole fish, as they do not penetrate the skin or bones. To enhance penetration into the meat, a massaging or "tumbling" system using vacuum or injection can be employed, especially for species such as tuna, catfish, and certain shellfish.[37,40,45,46] Compared to untreated samples, various types and concentrations of phosphate additives lead to increased yield values.[32,39,45,46,63] In this context, Ngoc et al.[68] observed that the optimum concentration (1.88% STPP) and soaking time (30 min) can be considered as a practical pretreatment to improve the quality of Pangasius fillets (i.e., weight gain and sensory characteristics) either fresh, chilled, or frozen storage.

The effects of compound phosphate on the water retention and nutritional quality of sea bass fillets were investigated by Zhi–Hui et al.[69] The water–holding capacity of the fillets treated with phosphate increased by 7.07% compared with the control group, and the fillets' quality improved. Additionally, after 30 to 120 min of "*in vitro*" simulated digestion, the protein digestibility in the digestion of steamed and fried fillets increased by 67.27 and 57.39%, respectively. It should also be noted that a combination of 1.4% STPP and 2.7% NaCl, according to Wangtueai et al,[70] can improve the shelf life of frozen Nile tilapia fillets for at least 8 months, since appearance and texture acceptability scores of treated fish were significantly higher than the control throughout storage. Also seeking to evaluate the effect of STPP and NaCl, alone or combined (1–2% STPP, 1–2%

NaCl), on the characteristics of weight changing, WHC, texture, DL, protein solubility, and color of frozen catfish fillet, Demayanti et al.[71] observed the best results on all parameters were obtained in the 2% STPP treatment with weight gain treatment at 11.38%, total weight gain (34.6%), shrink save (–7.55%), WHC (20%), DL (3.54%), and protein solubility (0.87%). The effect of phosphates on the gelation characteristics and water mobility of myofibrillar protein from grass carp (*Ctenopharyngodon idellus*) was evaluated by Huang et al.[72] at 4°C and 40°C. Increasing levels of phosphates reduced the elasticity and resistance of the gel, promoting greater fluidity. Furthermore, 0.02% TSPP or 0.04% STPP transformed the myofibrillar protein from a weak gel to a concentrated solution. The application of 4% STPP (20 minutes) and 10% STPP (1 minute) with the addition of 1% NaCl in scallops until the moisture reached 82% and 84%, respectively, demonstrated effectiveness in controlling DL during thawing and after cooking, along with a reduction in microbial count. Additional benefits were not achieved with extended exposure to STPP, whereas desirable functional effects were typically achieved with shorter exposure and without exceeding 83% moisture.[73]

The problematic issue in the phosphate's application

According to what has been presented so far, including the practical perception in the laboratory field in handling and preparing phosphate solutions, it is evident that not all sources of sodium tripolyphosphate (STPP) demonstrate equivalent or acceptable levels of insoluble substances and solubility characteristics. Caution is advised when using products from different sources with distinct raw materials and manufacturing processes.[18,38,90] Factors such as crystalline form, granulometry, and density can significantly impact the STPP performance, whether during solution preparation or application to seafood. The "time x concentration" factor requires thorough examination.[90] For the same product, immersion in a 5% phosphate solution necessitates a treatment time of 24 hours, while in a 25% solution, it only requires 2 seconds to achieve the same effect - namely, the inhibition of the formation of superficial protein clots and a reduction in loss through cooking.[18,38,44–46]

After reviewing numerous publications and evaluating the observations of each researcher, it is clear that there is a consensus on the precautions that should be taken before applying phosphates to different protein matrices (*i.e.*, different species of seafood) of various thicknesses and muscle types (*i.e.*, species variation) with different initial moisture contents. Caution is advised in the treatment of small–shelled shrimp, as excessive treatment may result in a transparent or glassy appearance and a slimy texture. The use of high levels of polyphosphates can impact processing and taste. A metallic taste, described as astringent, has been reported at levels exceeding 0.5%.[34,35,38,45,58,90,91] Additionally, the STPP solution may undergo hydrolysis to form orthophosphate in the presence of phosphatase, an enzyme found in meat.[18,28,38,42,92] If this occurs, orthophosphate can react with fatty acids, forming soaps with a distinctive taste. The problematic issue goes beyond the aspects of preparation and application, as the most important thing is to remain within legal limits and maintain consumer acceptance without affecting food safety.

Limits established in national and international legislation

Phosphates are used globally in the seafood industry and are legally permitted, if they are used according to specific conditions that do not exceed the maximum limits established by different countries.[18,38,44,45] Until July 2025, there was a restriction in Brazil regarding the use of phosphate in frozen seafood products, with its use permitted only in the glazing water. Up to that point, this limitation was seen as a barrier preventing the additive from fulfilling its beneficial functions in preserving seafood quality. Therefore, promoting research in this area was essential to demonstrate the technical, economic, and sanitary feasibility of using phosphate–based food additives in seafood products.

Considering that Brazil is a major importer and exporter of seafood, and based on the results of national and international studies related to phosphate use—as well as the approval of this additive by the Codex Alimentarius – starting in July 2025, phosphates were authorized by the Brazilian Health Regulatory Agency (ANVISA) for use in frozen–fish, –crustaceans, and –cephalopods,[42] as well as stabilizers on the outer coating through the glazing process.[93–96] On the other hand, the USA recognizes phosphate as GRAS (*Generally Recognized as Safe*),[43] while Canada[97] follows the recommendations of the Codex Alimentarius.[47,98] Therefore, Table 4 provides a summary of regulations concerning the use of phosphate food additives, detailing the maximum allowable dosages in seafood products.

Table 4 International and Brazilian legislation on phosphates limits.

Agência Nacional de Vigilância Sanitária[42]	Frozen fish, crustaceans, and cephalopods (2,200 mg/kg as phosphorus = 5,038 mg P_2O_5 /kg = 5 g P_2O_5 / kg)
Ministério da Agricultura e Pecuária[93-96]	Outer coating (glazing) of frozen fish, frozen shrimp, frozen lobster, frozen cephalopod mollusks to prevent cracking of glaze (0.5%; 5 g P_2O_5 / kg).
US Code of Federal Regulations[43]	GRAS (Generally Recognized as Safe) substance when used in accordance with Good Manufacturing Practices.
Health Canada[97]	Frozen clams; Frozen cooked shrimp; Frozen crab; Frozen fish fillets; Frozen lobster; Frozen minced fish; Frozen shrimp; Frozen squid - To reduce processing losses and to reduce thaw drip (in combination with other phosphates permitted by this list for the same purpose of use, the total added phosphate not to exceed 0.5% (5 g P_2O_5 / kg), calculated as sodium phosphate).
Codex Alimentarius[47,98]	Frozen fish, fish fillets, and fish products, including mollusks, crustaceans, and echinoderms. (2,200 mg/kg as phosphorus-5,038 mg P_2O_5 /kg– 5g P_2O_5 / kg

[a]Gadidae, Merluccidae; [b]Oreochromis sp.; Salmonidae; Clupeidae; Scombridae families; [c]Paralichthyidae; Ophidiidae; Serranidae; Pleuronectidae families.

When calculating the addition of phosphates, reference phosphate levels are typically employed. However, relying solely on average values may not be sufficient for accurately estimating added phosphates and ensuring compliance with legislation because there can be significant variations in phosphate content among individuals.[99] Based on available information in scientific literature, the residual phosphate content in seafood products has been demonstrated to fall within the acceptable legal limit of 5 g/kg as phosphorus peroxide (P_2O_5). Furthermore, it has been observed that the natural phosphorus content of seafood varies depending on the type of seafood.[18,33,40,41,46,100,101] From this perspective, a trend for the formulation of processed aquatic products is to reduce the inclusion levels of inorganic phosphates to use only what is necessary to obtain functional effects on meat proteins. Thus, several studies demonstrated that inclusion levels of 0.3% to 0.5% STPP were sufficient to perform the functional roles of inorganic phosphates in processed meat matrix systems.[27,33,40,41,46,60,90,91,102,103]

Can the physico–chemical characteristics of a product indicate potential adulteration with phosphate?

Brazil is highlighted as a major importer of seafood from regions including Asia, Europe, Russia, China, Vietnam, Canada, the USA, Peru, Chile, Argentina, Uruguay, and others. This country enforces stricter regulations concerning the identity and quality standards that seafood must meet to enter. However, notable instances of non–compliance have been observed in the seafood processing and import sectors, particularly in samples with pH levels and moisture/protein ratio (M/Pr) exceeding the limits established by Brazilian regulation (Table 5).

Table 5 Brazilian legislation for frozen fish, shrimp, lobster, and cephalopod mollusks.

Parameters	Frozen Fish[93]	Frozen Shrimp[94]	Frozen Lobster[95]	Frozen Cephalopod Mollusks[96]
pH	≤ 7.0 and ≤ 7.2[a]	≤ 7.85	≤ 7.85	≤ 6.85
Total phosphorous	≤ 5g P_2O_5/kg (Outer coating – glazing)	≤ 5g P_2O_5/kg (Outer coating – glazing)	≤ 5g P_2O_5/kg (Outer coating – glazing)	≤ 5g P_2O_5/kg (Outer coating – glazing)
Total Phosphorous[42]	≤ 2,200 mg P/kg (≤ 5g P2O5/kg)[42]	≤ 2,200 mg P/kg (≤ 5g P2O5/kg)[42]	≤ 2,200 mg P/kg (≤ 5g P2O5/kg) [42]	≤ 2,200 mg P/kg (≤ 5g P2O5/kg)[42]
Sodium	≤ 134 mg Na/100g	–	–	≤ 194 mg Na/100g (squid) ≤ 352 mg Na/100g (cuttlefish) ≤ 662 mg Na/100g (octopus)
Moisture/protein ratio	≤ 6,00 ≤ 5,00[b] ≤ 6,50[c]	– – –	– – –	– – –

This suggests that the pH parameter lacks differentiation for various seafood species, whose pH profiles vary based on their specific characteristics, composition, and post–mortem metabolism.[27] This underscores a regulatory gap in the monitoring of fish quality. Furthermore, relying solely on an instrumental method is not entirely dependable for evaluating the freshness and spoilage of seafood. According to scientific literature, pH measurement alone is not a reliable parameter for assessing the freshness of seafood.[10,17,104] Simultaneous analysis of chemical, microbiological, microscopic, and/or sensory factors is deemed necessary for more reliable results. Therefore, it is not considered valid to assess seafood suitability for consumption based solely on the pH parameter. No international legislation designates pH analysis as a definitive indicator of seafood freshness or as a criterion for deeming seafood unfit for consumption. The hydrogen ion potential (pH) serves to indicate the acidity, alkalinity, or neutrality of seafood muscle in an aqueous medium. Its determination is a key parameter in assessing the quality of various foods, including seafood, given that seafood is categorized as a low–acidity food (pH > 4.5). It's important to note that the concentration of hydrogen ions is often altered during hydrolytic, oxidative, or fermentative muscle decomposition.[10,48,105] Higher pH values correspond to increased bacterial activity.[10,17,104] The analysis is justified by the fact that fluctuations in pH values can induce partial denaturation of proteins, leading to a loss of their water–retaining capacity and subsequent exudation.[17,104]

Although numerous studies have examined the effects of phosphates on water retention, few have investigated the relationship between pH levels and the amount of added phosphate. Understanding the alkalinity of phosphate solutions (pH ~9.3), one might anticipate a proportional increase in muscle pH upon contact with seafood flesh. Lemos and Gonçalves[33] studied the effect of the STPP, and phosphate blend Carnal® 961 (3%, 5%, and 10%) in different contact times (30, 60, and 120 min.) on tuna meat pH, and the results showed a strong correlation between pH and phosphate content. Even with higher phosphate concentrations and contact times, the rise in pH corresponds to a rise in residual phosphate, yet it is still below the Brazilian regulatory limit of 7.0 for frozen fish (see Table 5). This indicates that pH alone is not a reliable indicator of phosphate misuse. Despite uncertainties regarding the rise in meat pH with the use of the additive, industries are currently producing phosphate blends that are typically buffered. Therefore, relying solely on pH evaluation to implicate the improper use of phosphate is a cause for concern. The pH changes suggest the need for confirmation through other chemical and microbiological parameters, such as total volatile basic nitrogen (TVB–N).[12–15,33]

Gonçalves, Souza, and Regis[46] reported compelling findings regarding pH and $\%P_2O_5$ values in both untreated and phosphate–treated Nile tilapia fillet samples. All additives employed resulted in reduced DL after the cooking process, showcasing their moisture retention capacity and potential as viable alternatives to STPP. Phosphate concentration increased with contact time in all phosphate treatments (0.28 to 0.56% for STPP and 0.2 to 0.46% for Phosphate Blend), remaining within international limits, i.e., 0.5% (5 g P_2O_5/kg). On the other hand, pH analysis revealed minimal variation across the different treatments.

Additionally, factors such as whether the seafood was frozen or subjected to freeze–thaw cycles should be considered, as they may influence the M/Pr results. This complexity highlights the challenge of establishing a universal limit for the M/Pr. Therefore, caution is necessary when considering this parameter (M/Pr) as a quality indicator or for inspection purposes. Considering the information regarding the M/Pr in seafood, Van–Ruth, Brouwer, and Koot[105] analyzed the M/Pr in various marketed products (with no information about the freezing process and posterior storage conditions), determining an average value of 4.8 (chilled shrimp) and 7.2 (frozen shrimp). In a study by Lemos and Gonçalves[33] using tuna meat, the relationship between phosphate treatments and moisture and protein contents was investigated. Although an increase in the M/Pr was observed, these values did not exceed the legal limits (5.0 to 6.0; see Table 5). This finding indicates that the M/Pr is not a conclusive indicator of fraud resulting from the improper use of phosphate.

The pH values and M/Pr observed after phosphate treatments are influenced by the initial pH of the muscle, as well as the initial moisture and protein content (*in natura*). Therefore, it is essential to conduct a critical review, with potential adjustments, of the official inspection parameters outlined in Brazilian legislation (pH and water/protein ratio) as indicators of the potentially abusive use of phosphate additives in seafood. This initiative aims to address and prevent fraud in frozen products. These proposed changes should be subject to validation through collaborative studies. Assessing the impact of temperature fluctuations in the seafood cold chain, including freezing, thawing, and refreezing, as well as common commercial practices involving multiple freeze–thaw cycles, Oliveira and Gonçalves[41] conducted an evaluation. The study aimed to determine the efficacy of various food additives in preserving the quality of shrimp *(L. vannamei*) after undergoing two freeze–thaw cycles. Simultaneously, the researchers investigated whether the moisture/protein ratio in both fresh and frozen–thawed shrimp, whether treated with additives or not, could serve as a useful indicator in detecting potential economic fraud through water addition. The phosphate treatment improved the quality of shrimp subjected to a freeze–thaw cycle. Non–phosphate food additives may also improve the quality of frozen white shrimp. The M/Pr acted harmoniously with the moisture and protein results. Two immersions and the different food additives used were determinants for the behavior of the variable's moisture, protein, M/Pr, WHC, pH, phosphate, and sodium content. A single immersion of the samples in food additives was associated with higher values of WHC, moisture, and protein, while two immersions were associated with the highest M/Pr, pH, phosphate, and sodium values. Even when using all additives at the concentrations and times specified in this study, an increase in the M/Pr ratio was observed in frozen shrimp meat. However, it could not be used as an indicator of economic fraud by the addition of water since the M/Pr ratio was below the limits set by Brazilian regulations.[33,93]

Based on what has been presented so far, a questioning, or rather, a reflection is suggested: "*If an analysis specifically targeting polyphosphates (not total phosphorus) in a certain seafood sample fails to detect triphosphate, pyrophosphate, and trimetaphosphate, with only orthophosphate (simple phosphate) being identified, along with a low sodium value (high sodium levels could be attributed to sodium release during polyphosphate hydrolysis) and a pH below neutrality (raising questions about the presence of phosphates), could these results suggest a lack of evidence of adulteration?*"

In addition to phosphorus accumulating in muscle tissue due to ATP breakdown during the postmortem period of seafood,[12,18] and the presence of phosphorus compounds like nucleotides and phospholipids, as well as naturally occurring orthophosphates, another potential factor to consider is the presence of intramuscular spines in the portion being analyzed.[2,17] In this scenario, the natural presence of phosphorus has sparked debate, casting doubt on whether seafood might have been treated with phosphate food additives. Within cells, phosphates play a role in metabolic functions, serving as an energy source.[16,106] Quantifying "added" phosphates in seafood poses challenges because it is necessary to distinguish between levels of naturally occurring phosphates, which are not well defined in scientific literature due to their variability, and the level of added phosphate.[99] Attempts to use measurements of moisture content or phosphates (such as phosphorus) have been deemed inadequate to demonstrate the addition of phosphates to products, primarily due to their substantial natural variation.[21]

It is important to highlight that relying solely on phosphate quantification is insufficient for confirming the presence of added phosphate. This is because naturally occurring orthophosphates and other phosphorus compounds are present in muscle tissue. Moreover, there is considerable biological variation in total phosphorus content among individuals. Another consideration is that when added to seafood, polyphosphates undergo chemical and enzymatic degradation facilitated by muscle phosphatase. This process converts them into orthophosphates, particularly pyrophosphate and triphosphate. The rate of degradation is influenced by various factors, including phosphate type, muscle species, enzymes, other ingredients, processing methods, storage conditions, and storage time.[27] The hydrolysis process is influenced by the sample preparation method during analysis. Hydrolysis occurs more slowly when whole muscle is injected with phosphates compared to mechanically mixing separated meat with phosphates, as the latter increases enzyme access to the substrate. The rate of breakdown also increases with rising temperature, even occurring at 0°C. However, there is only a slight decrease in polyphosphate levels in cooked products stored frozen for up to 11 months, possibly due to the inactivation of phosphatases during cooking.[21] It is important to reiterate that if phosphate were added, it would likely be detectable in High–Performance Liquid Chromatographic (HPLC) analysis.[107] Additionally, freezing slows down enzymatic activity. After thawing, the Tpase activity of frozen meat resembles that of unfrozen meat. However, the freezing and thawing process causes reversible inhibition of dipolyphosphatase (Dpase) activity, and the reactivation of this activity depends on the muscle pH.[43] Therefore, in the case of frozen seafood, any added phosphate would not be rapidly hydrolyzed into smaller phosphates (orthophosphates), making it detectable in HPLC analysis. For a better understanding of the methods used in phosphate analysis, some of them will be presented in section "Total phosphorus analysis".

How do polyphosphates decomposition over time and what are the resulting decomposition products?

Most polyphosphates added to food break down into individual phosphate units (orthophosphates), either during consumption or before consumption. This can happen in the stomach, during cold storage, or during cooking.[37] Sutton[108] demonstrated that tripolyphosphates rapidly hydrolyze to pyrophosphates and subsequently to orthophosphate in raw muscle, primarily through the action of phosphatase at temperatures of 0 and 25°C. The breakdown of tripolyphosphate occurs rapidly at 25°C, with a significantly reduced rate at 0°C. In raw cod stored at 0°C, pyrophosphate was no longer detectable after 30–40 hours, although orthophosphate remained detectable. Experiments conducted by Tenhet et al.[109] revealed that, after two weeks of frozen storage, only 12% of the total phosphorus in uncooked shrimp muscle corresponded to the originally added tripolyphosphate. After ten weeks of frozen storage, phosphorus levels equated to 45% orthophosphate. This is likely attributed to natural hydrolysis, and no heat treatment was employed to facilitate the hydrolysis of tripolyphosphates. During steaming and other processes involving elevated temperatures, sodium tripolyphosphates undergo rapid and efficient hydrolysis, converting into orthophosphates. Orthophosphates, unlike polyphosphates, do not contribute to water binding and, therefore, do not enhance water retention in meat. Heitkemper et al.[110] examined samples of various commercially available cooked shrimp treated with tripolyphosphate and stored frozen for 11 months.

The concentrations of tripolyphosphate and polyphosphate were assessed before and after storage. The total polyphosphate concentration observed after 11 months of frozen storage ranged from 87% to 103% of the initial values, indicating minimal hydrolysis during the frozen storage period. The authors also noted significant hydrolysis in uncooked products due to enzymatic action. In two uncooked samples stored at refrigerated temperatures, the tripolyphosphate concentration decreased from around 2.5 g P_2O_5/kg to below the limit of detection (0.5 g P_2O_5/kg) within 3 days. In a study by Kaufmann et al.[111] assessing the stability of polyphosphates in fish and shrimp under various conditions (untreated, treated, 1 day after treatment, 2 days after treatment, and 3 days after treatment), ion chromatography analysis revealed that in raw shrimp stored at 4°C, polyphosphate levels decreased from approximately 1.5 g P_2O_5/kg to zero after 4 days. However, in previously cooked shrimp treated with polyphosphate after cooking, no degradation of polyphosphates was observed. The initial concentrations of polyphosphates measured in cooked and treated shrimp were higher than in raw shrimp (2.6 and 1.5 g P_2O_5/kg, respectively). This difference was attributed to the rapid enzymatic degradation of polyphosphate in raw shrimp by the action of the phosphatase enzyme. The lack of degradation in cooked shrimp was attributed to phosphatase inactivation during the cooking process.

Incorporation of phosphate in seafood vs. sodium content

Before discussing this topic, it is important to note that Brazilian legislation limits the sodium content in frozen fish[93] and cephalopod mollusks[96] within the parameters of identity and quality (Table 5). This has caused disagreements among the production sector, importers, and regulatory agencies.

Understanding the chemical characteristics of phosphates, particularly those containing sodium (such as 339 – Sodium Phosphates; 450 - Diphosphates; 451 - Triphosphates; and 452 - Polyphosphates), is a fundamental requirement for assessing the sodium levels in samples. This evaluation is essential to quantify the natural concentration of sodium in untreated samples and those treated with phosphates. The aim is to examine the incorporation of sodium, highlighting its significance. It is worth highlighting that in developed nations, approximately 75% of the sodium consumed originates from processed foods and meals consumed outside the home. In Asia and many African countries, salt used in cooking and found in sauces and seasonings constitutes the primary source of dietary sodium.[112] Fundamental foods like meat, seafood, vegetables, and greens naturally contain relatively low sodium ion levels (averaging around 100 mg Na/100 g), and cereals typically have trace amounts. The sodium content (mg Na/100g) varies widely in processed foods: salted cod (7,000), French fries (231–700), cream cracker biscuits (683–919), water and salt biscuits (632–1,145), mayonnaise (760–1,218), bread (411–880), instant noodles (1,153–3,320), mozzarella cheese (331–1,027), and parmesan cheese (580–1,787).[113]

Considering that numerous food items available to the public contain elevated sodium levels and the recommended daily sodium intake by the World Health Organization (WHO)[112] should be below 2,000 mg Na, it's important to define high-sodium foods as those with an amount ≥400 mg Na/100 g. Notably, there is a scarcity of scientific studies exclusively addressing sodium quantification in fresh or frozen fish in both national and international scientific literature. The variation in sodium values within food composition databases adds complexity. Both national and international practices for ensuring seafood quality involve using food–grade additives, such as phosphates, or immersing seafood in saline solutions (brine) or refrigerated seawater before processing. These practices have significant technological implications and may elevate sodium levels. However, they typically do not exceed the recommended daily sodium intake limit of 2,000 mg/day.[112]

Although there is no limit on sodium content for shrimp or lobster in Brazilian regulation (only for fish and cephalopod mollusks, see Table 5), and considering the possibility of an increase in sodium content due to phosphate treatment, Damasceno and Gonçalves[40] reported the sodium content in raw shell–on shrimp treated with 5% STPP and 5% phosphate blend – CARNAL® 961 (60 min.) and reveal a gradual increase in sodium percentages during the treatment process. The natural sodium content found in raw and treated shrimp (STPP and C–961) was 63 mg Na/100 g, 89 mg Na/100 g, and 250 mg Na/100 g, respectively. On the other hand, Oliveira and Gonçalves[41] presented the sodium content in raw peeled shrimp samples after two cycles of freezing and thawing treated with 5% STPP and 5% phosphate blend – CARNAL® 961 (60 min.) and found an escalation in sodium percentages in shrimp: 117.8 mg Na/100 g (raw), 274.4 mg Na/100 g (STPP, 1st immersion), 314.2 mg Na/100 g (STPP, 2nd immersion), 133.6 mg Na/100 g (C–961, 1st immersion), and 522.6 mg Na/100 g (C–961, 2nd immersion). Finally, considering that Brazilian legislation limits sodium content (134 mg Na/100g for fish, 194 mg Na/100g for squid, 352 mg Na/100g for cuttlefish, and 662 mg Na/100g for octopus; Table 5), and assuming there is a 100% or 200% increase in sodium content due to any technological practices (such as immersion in brine or a phosphate solution to prevent liquid loss during thawing), and if the daily consumption portion of any species is ~100g, the resulting sodium levels would remain below the daily sodium intake limit recommended by the WHO (< 2000 mg Na/day). While such increases wouldn't pose a health risk to consumers, they should be disclosed in the Nutritional Facts on the label and not limited by any regulation.

Scientific studies addressing the sodium content in aquatic food

There is a limited number of studies in both the national and international scientific literature that are exclusively dedicated to quantifying sodium levels in fresh (chilled) or frozen seafood. Many of these works focus primarily on seafood products and those with reduced sodium content. Dr. Contreras–Guzmán[31] highlights that the sodium content in Brazilian and Chilean fish (Southern Hemisphere) is notably higher (119.3 and 167.1 mg Na/100 g, respectively) than the general average (63 mg Na/100 g). This discrepancy is attributed to dietary habits, which emphasizes the importance of understanding seasonal variations in chemical composition for technological purposes. Furthermore, Contreras–Guzmán[31] notes that variations in species' chemical composition induced by occasional physiological states are commonplace and accepted by analysts, provided meticulous sampling is used to prevent errors that exceed natural fluctuations. Additionally, there exists inherent variability in the chemical constituents within fish meat, with each species having a distinct centesimal composition. This diversity complicates dietary assessments when relying solely on analytical portions.[27] The author emphasizes that the considerable variation in mineral content discourages making comparisons between different classes of seafood. Interestingly, fish from New Zealand also exhibit elevated sodium levels, akin to data from South America, supporting the hypothesis that fish from the Southern Hemisphere tend to have higher sodium levels. According to Dr. Venugopal,[2] most fresh marine fish can be considered a moderately low–sodium food, providing about 140 mg of sodium per serving (approximately 100–150 g). However, the sodium content of most processed fish and seafood products (frozen, canned, smoked, and cured) can be substantially high, ranging from 300 to 900 mg Na/100 g. In a survey study of 96 marine species (fish, mollusks, and crustaceans) from the Northeast Atlantic, Rodrigues et al.[7] and Durazzo et al.[4] inform that potassium, phosphorus, and sodium were indicated as being prevalent macrominerals, while zinc, iron, and copper were the most abundant trace elements. In the same study, for sodium, the minimum mean concentration was 230 mg Na/kg in *Scomber colias*, whereas the maximum was in *Thunnus albacares* (7,410 mg Na/kg).

To illustrate the variability in sodium content in seafood, some of the primary international databases on the nutritional value of foods were consulted (Table 6). For example, the USDA Food Composition Databases reveal that the sodium levels of various raw fish species can vary significantly, ranging from 18 to 296 milligrams of sodium per 100 grams. This wide range highlights the difficulty in establishing a universal maximum sodium limit for the "fish" category.

Table 6 Sodium content (mg Na/100g) in raw fish (average; min – max values; n = sample number).

80.48 (18 – 296) n = 63	United States Department of Agriculture Agricultural Research Service National Nutrient Database for Standard Reference Release 28 (https://ndb.nal.usda.gov/ndb/search/list)
108.17 (66 – 204) n = 12	UK Department of Health, Nutrient analysis of fish and fish products Analytical Report (http://www.dh.gov.uk/publications)
80.92 (68 – 91) n = 12	Tabla de Composición de Alimentos - I° Edición - © 2010 Universidad Nacional de Luján (http://www.argenfoods.unlu.edu.ar/Tablas/Tabla.htm)
146.46 (55 – 584) n = 13	ASEAN Food Composition Database Electronic version 1, Feb 2014 (http://www.inmu.mahidol.ac.th/aseanfoods/composition_data.html)
107.64 (44 – 333) n = 33	Government of Canada, Food and Nutrition Nutrition | Healthy Eating Canadian Nutrient File (https://food-nutrition.canada.ca/cnf-fce/index-eng.jsp)
123.52 (33 – 594) n = 25	Nubel (Nutrients Belgium) Product Groups 2. Fish, molluscs, and crustaceans | 2.1. Fresh fish, molluscs, and crustaceans (http://www.internubel.be/Groups.aspx?lId=3andgId=63andmgId=60)
91.02 (30 –357) n = 41	FAO/INFOODS Global Food Composition Database for Fish and Shellfish (uFiSh1.0) (http://www.fao.org/fileadmin/templates/food_composition/documents/uFiSh1.0.xlsx)

*Using the factor 2.29 (P to P_2O_5 conversion) – see section 5.1

In a study conducted by the Institute of Food Research, Department of Health (United Kingdom), researchers Roe et al.[114] assessed the nutritional composition of 56 fish species, and specifically focusing on the sodium content in samples of fresh (raw) fish, the results revealed a significant range in sodium values (between 66 and 204 mg Na/100 g), consistent with findings from the USDA Food Composition Databases. Additionally, Table 6 illustrates a notable variability in sodium content across raw fish species, with many exceeding the sodium limit specified by Brazilian legislation (134 mg Na/100 g; Table 5).[93]

Phosphate analysis in seafood - A problem to be solved.

Recently, disagreements have arisen regarding the methods used to prepare seafood samples for physical–chemical analyses. The Official Methods of Analysis by AOAC International serves as a global resource for methods, with contributions from scientists worldwide for standard development, method creation, and the systematic evaluation of methods. AOAC International boasts the most comprehensive collection of chemical and microbiological methods globally. Many methods within this compendium are denoted as internationally recognized reference methods, harmonized by organizations such as the International Organization for Standardization (ISO), International Dairy Federation (IDF), International Union of Pure and Applied Chemistry (IUPAC), and Codex Alimentarius Commission. In accordance with the AOAC International Official Method for Seafood and Other Marine Products,[115] for frozen seafood samples, the standard recommends thawing the sample at room temperature and discarding the exudate, which is the liquid produced during thawing. This liquid is typically discarded before preparing any food of animal origin. A critical point to consider is that this procedure, independent of additional analyses like total phosphorus, is designed to yield a true quantification per 100 g of sample, minimizing the risk of overestimation. This precaution ensures accurate quantification and distinguishes the results from those obtained using a frozen sample (muscle + exudate).

Contrarily, the Brazilian Manual of Official Methods for the Analysis of Food of Animal Origin[116] recommends a different approach for frozen seafood. The suggestion is to solely remove the glazing from the sample while keeping it frozen. This method aims to prevent the loss of sodium and potassium and the degradation of polyphosphates that may occur during the thawing process. This approach considers the quantification of the desired parameter within the analytical sample (muscle + exudate). It differs significantly from the previous thawing and exudate–discarding method, where all analyzed parameters may exhibit overestimated values – a departure from AOAC recommendations followed by researchers. In addition, the ISO 3100–1:1991 method, titled "*Meat and meat products – Sampling and preparation of test samples – Part I: Sampling*," furnishes comprehensive guidelines for both general and specific procedures to be observed during the primary sampling of meat and meat products. However, this standard does not provide details on the subsequent sample preparation procedure for further analysis. This is particularly true when it comes to removing potential interferences, such as intermuscular spines, and according to Venugopal[2], bone structures have high levels of phosphorus.

Total phosphorus analysis

According to the information presented so far, the phosphate additives in food products were limited to controlled amounts. Various methods have been developed to detect phosphates, including chromatography, colorimetry, and fluorescence.[29,117] Seafood products naturally contain orthophosphates, which can also rise in processed items due to the breakdown of added inorganic polyphosphates. Therefore, it is fundamental to distinguish between naturally occurring and added inorganic phosphates to enable accurate assessment of the latter.[99] The development of more specific analytical methods for the determination of phosphates was strongly encouraged by the EFSA Scientific Committee report.[118] The assessment of total phosphate (as P_2O_5) content in meat and seafood typically relies on the quantification of phosphorus through spectrophotometric analysis. In the process of phosphorus quantification, spectroscopy is employed to gauge the color generated by the reaction of orthophosphates with specific chemicals. Common methods utilizing this approach include the molybdenum blue method, the yellow vanadomolybdate complex method, and the malachite green method.[119] The intensity of color observed is directly proportional to the concentration of phosphorus. It's important to note that quantifying phosphorus through spectroscopy requires breaking down polyphosphates and other phosphorus forms into orthophosphates. This is achieved in the presence of sulfuric or trichloroacetic acid. Spectrophotometric methods for determining total phosphorus have undergone enhancements to enhance sensitivity and precision, as summarized by Jastrzębska and Szlyk.[119] However, relying solely on phosphorus quantification cannot definitively confirm the addition of phosphates to seafood, as natural orthophosphates and other phosphorus–containing compounds are naturally present.[21] Moreover, research indicates substantial natural variability in total phosphorus content among individuals.[120] The traditional colorimetric determination of total phosphorus content (mg P/100 g) in products of animal origin employs a conversion factor of "**2.29**" for total phosphorus (P) to phosphate (P_2O_5) (mg P_2O_5/100 g). But *how is this conversion of total phosphorus (P) to phosphate (P_2O_5) carried out?* Considering the atomic weights of phosphorus (31) and oxygen (16), along with their P_2 equivalence in P_2O_5, the calculation is as follows:

P_2	—	P_2O_5
(31 x 2)	—	(31 x 2) + (16 x 5)
62	—	142
		142/62 = **2.2903**

Therefore, the validity of the factor **2.29** (P to P_2O_5 conversion) hinges on the assumption that all quantified phosphorus (P) in the sample originates solely from its phosphate form (P_2O_5), which is not the case. In this situation, utilizing this conversion factor incorrectly leads to overestimated results. However, Boiţeanu and Neacsu[19] also report that the maximum quantity of added phosphates allowed in frozen products is 5 g P_2O_5/kg, which can be calculated as phosphorus pentoxide ($P_2O_5 \approx 2.29 \times P$) and orthophosphate ($PO_4^{3-} \approx 3.06 \times P$). In line with the Analytical Norms of the Adolfo Lutz Institute,[121] which quantifies phosphorus content in foods (398/IV Determination of phosphorus by spectrophotometry in the visible region), the method relies on the complexation of phosphorus with ammonium vanado–molybdate, followed by determination through spectrophotometry in the visible region. The calculated phosphorus amount is expressed in mg P/100 g, and the conversion factor of 2.29 is also applied for the conversion of total phosphorus (P) to phosphate (P_2O_5). Furthermore, it is essential to recognize that, according to scientific literature, natural phosphorus in seafood does not occur solely in the form of phosphate (PO_4^{3-} or P_2O_5). It includes various phosphorus compounds, such as nucleotides, phospholipids, phosphatides, and naturally occurring orthophosphates. These concentrations can vary significantly based on factors such as species, individuals within the same species, feeding habits, reproductive stages, geographic locations, etc., ranging from 0.68 to 5.5 g/kg.[16,18,120,122]

In the Brazilian Manual of Official Methods for the Analysis of Foods of Animal Origin,[116] the analysis of total phosphorus follows the ISO 13730:1996 standard, titled "*Meat and meat products – Determination of total phosphorous content – Spectrometric method.*" This method, though international, does not explicitly address seafood unless categorized under "meat." The accuracy results mentioned are specific to processed sausages. Total phosphorus content is expressed as phosphorus pentoxide (P_2O_5) mass, expressed as a percentage. However, assuming all phosphorus is in phosphate form can overestimate P_2O_5 values, as not all phosphorus exists this way in meat. In ISO 13730:2021 *(Meat and meat products - Determination of total phosphorus content*), three methods are outlined for assessing phosphorus in all meat types: inductively coupled plasma optical emission spectrometry (ICP–OES), spectrometric, and gravimetric. The process includes a calcination step at 550°C to prepare the sample, yielding diverse inorganic mineral elements in the residue. This variation complicates species identification based on mineral composition, as noted by Contreras–Guzmán.[31] However, such fluctuations are acceptable with careful sampling, ensuring errors remain within natural variability.

Chromatographic methods, including thin–layer chromatography (TLC), detect and sometimes quantify added phosphate in foods. Chromatography separates mixtures into components via a stationary phase (solid or liquid supported on solid) and a mobile phase (liquid or gas). TLC can isolate various polyphosphates (ortho-, pyro-, tri-, and polyphosphates) from one sample. Its advantages include simplicity, rapid analysis (within hours), and cost–effectiveness.[123] However, hydrolysis during sample preparation and analysis can affect results. For example, one mole of tripolyphosphate hydrolyzes to one mole of orthophosphate and one mole of pyrophosphate, while one mole of pyrophosphate hydrolyzes to two moles of orthophosphate.[110] Near Infrared Spectroscopy (NIR) is a dependable, quick, and non–invasive method for assessing food quality. Todd[28] employed NIR to identify shrimp treated with sodium tripolyphosphate. While the initial findings from the NIR analysis showed promise, further investigation is needed to confirm if this method is suitable for detecting sodium tripolyphosphate in treated shrimp. Ion chromatography (IC), a variant of high–performance liquid chromatography (HPLC), employs an ion exchange resin–filled column as the stationary phase, with an active material coating its surface. The ions in the sample move through the column via the eluent – a conductive solution, such as an acid or hydroxide – producing distinct retention times for the components. This process generates a chromatogram, graphing ion abundance against retention time. IC effectively discerns polyphosphates (ortho-, pyro-, tri-, and polyphosphates) with quantitative results, offering reproducible data swiftly, typically within hours. Recent advancements have resolved issues related to false positive and negative results,[22,111] positioning ion chromatography as one of the most widely used methods for routine screening of food samples for phosphate additions.[124] when evaluating the presence of polyphosphates in seafood using high–performance ion–exchange chromatography with suppressed conductometry (HPIEC–SCD) coupled to Q-Exactive Orbitrap high-resolution mass spectrometry (HRMS-Orbitrap) in different categories of fishery and processed marine food products, as well as their relevance to food safety, noted that unambiguous hexametaphosphate presence was demonstrated in four prawn samples, while triphosphate was quantified (11.20±4 µg/g) in another four prawn samples that contained orthophosphate (10,23±1,102 µg/g), as well. Other samples sporadically encompassed polyphosphate profiles that varied according to species and processing type. Nuclear magnetic resonance - NMR (particularly 31P NMR) has traditionally been used as a research tool rather than a routine analytical procedure. However, it is becoming more available and affordable. 31P NMR offers the unique ability to differentiate between various types of phosphate and provide quantitative analysis simultaneously. Despite challenges like polyphosphate degradation, its non-destructive nature and simultaneous observation of different phosphate species offer clear analytical advantages, making it applicable to fish and meat products with adequate sensitivity. While 31P NMR can measure total phosphates or polyphosphates, it cannot distinguish between natural and added compounds.[118] Fluorescent methods have been gaining increasing attention due to their high sensitivity.[23,125] Typically, these methods for detecting phosphates rely on the coordination interaction between phosphate ions and fluorescent probes.[126] Given that phosphates are widely employed in food additives, there remains a strong demand for developing new sensing strategies for phosphate detection. Recently, He et al.[117] introduced a method for determining phosphates added to frozen shrimp samples using ratiometric fluorescent detection, yielding satisfactory results.

Phosphorus content in seafood

Accurate, dependable, and current food composition data play a pivotal role not only in nutrition, dietetics, and health but also across various disciplines such as food science, biodiversity, plant breeding, the food industry, trade, and food regulation. Utilizing a food composition table database necessitates a critical awareness of the potential for significant variations in nutritional composition attributed to natural factors (e.g., soil, genetics, climate) or artificial distinctions (*e.g.*, nutrient definitions or expressions, enrichment, fortification).[127]

Inadequate food composition data and their application can result in erroneous research outcomes and misguided policy decisions - especially in areas like nutrition, agriculture, and health-misleading food labels, unfounded health claims, and suboptimal food choices.[127] Greenfield and Southgate[123] and FAO[128] identify the three fundamental pillars for ensuring high-quality food composition data: (*i*) Adherence to international standards and guidelines governing the generation and compilation of food composition data; (*ii*) The existence of national and/or regional food composition programs, coupled with regular updates to food composition tables/databases; (*iii*) Comprehensive training of professionals in all facets related to food composition.

According to the International Network of Food Data Systems,[127] markedly influenced by environmental, genetic, and processing factors, including feed, soil, climate, genetic resources (varieties/cultivars, breeds), storage conditions, processing, fortification, and market share. Each country possesses specific data needs due to the distinct compositions of its foods, challenging the assumption that foods have similar compositions globally. This underscores that nutrient content can vary as much among different foods as among varieties of the same food. Seafood naturally contains phosphates and thus phosphorus. Detecting the level of added polyphosphates solely through measuring phosphate or phosphorus is challenging because naturally occurring levels vary widely.[16]

Since it's not possible to determine the natural phosphate content of a sample before processing, consideration of variations in unprocessed samples is necessary. This ensures that the calculated amount of added phosphates is not confusing with the natural amount. The results can then be reported as "at least a specific amount of phosphates was added to the product," which ensures the quality of the results. This issue arises because legislation usually focuses on regulating the amount of added phosphates rather than the total phosphate content of a product.[99]

To illustrate the variability in phosphorus levels in raw fish, a review of 132 international databases on the nutritional value of foods was conducted. Among these, 11 databases (referenced in Table 7) provided information on phosphorus levels (which were transformed into P_2O_5 - using the factor 2.29 - P→ P_2O_5), revealing significant variation in the 654 values obtained (ranging from 1.90 to 27.48 g P_2O_5/kg). Notably, ~ 45% of these values exceeded 5 g P_2O_5/kg, emphasizing the technical challenge in establishing a definitive cut-off point or phosphorus limit for the "fish" category.

Table 7 Total phosphorus content (mg P/100g) and total phosphates content (g P_2O_5/kg)* in raw fish in international food composition databases (average; min – max values; n = sample number).

80.48 (18 – 296) n = 63	United States Department of Agriculture Agricultural Research Service National Nutrient Database for Standard Reference Release 28 (https://ndb.nal.usda.gov/ndb/search/list)
108.17 (66 – 204) n = 12	UK Department of Health, Nutrient analysis of fish and fish products Analytical Report (http://www.dh.gov.uk/publications)
80.92 (68 – 91) n = 12	Tabla de Composición de Alimentos - I° Edición - © 2010 Universidad Nacional de Luján (http://www.argenfoods.unlu.edu.ar/Tablas/Tabla.htm)
146.46 (55 – 584) n = 13	ASEAN Food Composition Database Electronic version 1, Feb 2014 (http://www.inmu.mahidol.ac.th/aseanfoods/composition_data.html)
107.64 (44 – 333) n = 33	Government of Canada, Food and Nutrition Nutrition | Healthy Eating Canadian Nutrient File (https://food-nutrition.canada.ca/cnf-fce/index-eng.jsp)

Table 9 Continued...

123.52 (33 – 594) n = 25	Nubel (Nutrients Belgium) Product Groups 2. Fish, molluscs, and crustaceans | 2.1. Fresh fish, molluscs, and crustaceans (http://www.internubel.be/Groups.aspx?lId=3andgId=63andmgId=60)
91.02 (30 –357) n = 41	FAO/INFOODS Global Food Composition Database for Fish and Shellfish (uFiSh1.0) (http://www.fao.org/fileadmin/templates/food_composition/documents/uFiSh1.0.xlsx)

Using the factor 2.29 (P to P_2O_5 conversion) – see section 5.1

In addition, Teixeira et al.[99] examined the natural phosphate levels in various unprocessed seafood species, including octopus, cuttlefish, Norway lobster, sea bass, gilthead sea bream, hake, and rainbow trout. They found that phosphate levels varied among species, with octopus and turbot having the lowest average values (3.8 g P_2O_5/kg and 4.0 P_2O_5/kg, respectively) and chub mackerel and sardine having the highest (6.4 P_2O_5/kg and 6.6 P_2O_5/kg, respectively). Notably, the phosphate content in Norway lobster was higher in this study (5.7 P_2O_5/kg). The study's large sample size (n = 46) likely provided a more accurate and current representation of natural phosphate levels in Norway lobster. The greatest variations in natural phosphate content could be attributed to various factors not yet described.

Even though there were variations in phosphate content noted in the studies presented throughout this review, probably due to the lack of specific legislation, they indicate that the practice of adding phosphates to seafood products isn't widespread across several countries. However, some seafood samples did contain added phosphates, although the majority stayed within legal limits. With the industry's increasing use of phosphates and for consumer safety, it's wise to include information about phosphate content on product labels. To make regulation easier, it would be better to set limits based on total phosphate content (natural + added).

Health risk of phosphate intake

The European Food Safety Authority (EFSA) received a request from the European Commission to conduct a scientific assessment addressing concerns raised in the scientific article "Phosphate additives in food: a health risk".[129] This document suggested a potential link between elevated intake of phosphates as food additives and an increased cardiovascular risk in the general population. The authors emphasize the significance of phosphate intake through the consumption of ready-to-eat processed foods for the entire population, as recent studies have indicated that it may be considerably higher than previously estimated. In their conclusions, the authors recommend implementing labeling requirements for foods containing added phosphates, considering the potential adverse effects linked to excessive phosphate intake. Additionally, some studies in the published literature, including those by Ritz et al.[129], have presented inconsistent or contrasting results in a narrative format. Ideally, a meta-analysis or systematic review of the available literature could aid in interpreting these findings. Phosphoric acid and phosphates (INS 338-341; INS 343), as well as polyphosphates (INS 450-452), are authorized additives used for various technological purposes in numerous food products. Uribarri[130] informs that phosphorus is prominently present in protein-rich foods, with notable levels found in dairy products (100-900 mg P/100 g), meats (200 mg P/100 g), fish (200 mg P/100 g or 0.458 g P_2O_5/100 g), and grains (100-300 mg/100 g), and the bioavailability of phosphorus is contingent on the food source. In addition, the average daily consumption of phosphorus in adults is estimated to be between 1 and 2 g P/day.[131] Further on, the Expert Group on Vitamins and Minerals (EVM) further concluded that a total intake of 2.4 g/day (considering 2.11 g/day of inorganic phosphorus from food, including food additives and water, and 0.25 g/day from supplemental phosphorus) does not result in any adverse effects.[118] The reference phosphorus intake for adults has been established at 550 mg/day by the Scientific Committee on Food (SCF).[132] The US Institute of Medicine has set nutritional recommendations ranging from 460 to 1,250 mg of phosphorus per day for different age groups. In 2005, the European Food Safety Authority's Panel on Dietetic Products, Nutrition, and Allergies[133] was unable to determine a tolerable intake level for phosphorus. However, they concluded that healthy individuals could tolerate a phosphorus intake of at least 3,000 mg per day without experiencing systemic adverse effects. Phosphates, diphosphates, and polyphosphates have undergone evaluations for use as food additives by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) on multiple occasions.[134-142] The Maximum Tolerable Daily Intake (MTDI) of 70 mg P/kg body weight (b/w), expressed as phosphorus, for the sum of phosphates and polyphosphates, both naturally present in food and ingested as food additives, previously proposed by the JEFCA, was established during the 26th JECFA Meeting, considering the lowest dietary concentration of phosphorus (1% in the diet) that induced nephrocalcinosis in rats. During its assessment, JECFA deemed it inappropriate to establish an Acceptable Daily Intake (ADI) for phosphorus, primarily in the form of phosphate, is an essential nutrient and an unavoidable component of food.

The MTDI, expressed as phosphorus, encompasses both the phosphates naturally occurring in foods and those derived from the use of food additives. This criterion is specified as follows: "The MTDI applies to diets that are nutritionally adequate with respect to calcium. However, if calcium intake is high, phosphate intake may be proportionately higher, and the inverse relationship is equally applicable".[141] The Scientific Committee on Food (SCF) has evaluated phosphoric acid and its salts on multiple occasions.[132,143–145] The SCF endorsed the JECFA conclusions, establishing an MTDI of 70 mg P/kg body weight from all sources, expressed as P (equivalent to 160.32 mg of P_2O_5), for orthophosphoric acid and its sodium, potassium, calcium, magnesium, and ammonium phosphates, as well as for di-, tri-, and polyphosphates. The recent EFSA scientific opinion[60] highlighted that (poly)phosphates exhibit low acute oral toxicity and pose no genotoxic or carcinogenic concerns. However, their intake through processed foods must be carefully regulated due to potential traces of toxic metals such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg).

According to Calvo, Sherman, and Uribarri[146] and Calvo, Dunford, and Uribarri,[20] inorganic phosphate additives contribute to excessive phosphate intake, and there is increasing evidence of its association with adverse health effects in the otherwise healthy general population. However, although inorganic phosphates are low in toxicity, an intake of less than 1,000 mg per day is recommended.[60,129,147]

Highlighting critical issues and challenges that should be considered regarding the uses of phosphates in the seafood industry

Based on what has been presented, it is important to emphasize that using phosphate in the seafood industry is key to improving and preserving the quality of frozen and cooked seafood while minimizing weight and nutrient loss. For this reason, the following critical issues are presented.

i. Phosphorus, as a widely distributed mineral in nature, plays crucial metabolic roles in organisms, including the development of bone structure, activation, regulation, transmission, and control;
ii. Adenosine triphosphate (ATP) acts as the primary energy carrier in living organisms, providing energy for metabolic processes;
iii. The natural presence of phosphorus has sparked debate, casting doubt on whether seafood might have been treated with phosphate food additives;
iv. Ensuring a stable and safe product is crucial for technological development and constant product improvement;
v. Improper phosphate use can lead to sensory defects and charges of economic fraud;
vi. There is a need for better information on the responsible use of phosphate additives in the industry, with regulatory agencies and consumers being vigilant about potential abuses;
vii. Food additive and ingredient companies, as well as seafood processors, express dissatisfaction with the inconsistent use of phosphates and call for a consistent study;
viii. The use of additives should be limited to specific foods, under specific conditions, and at the lowest effective level, as proven by research institutions;
ix. Phosphates have been toxicologically evaluated by JECFA, which established a Maximum Tolerable Daily Intake (MTDI) of 70 mg of phosphorus per kilogram of body weight since 1982;
x. Compliance with Codex Alimentarius, a major regulation for food-grade additives, is essential, with Brazil as a signatory following its recommendations;
xi. The use of food-grade phosphate additives in seafood is considered permissible, logically with a scientific and technical basis, and without current restrictions, aligning with its equivalence with meat;
xii. The primary concern of Brazilian authorities is the illegal use of phosphates to incorporate water and weight into products, deceiving consumers;
xiii. The additive is permitted in several countries and listed as an ingredient alongside seafood, water, and tripolyphosphate;
xiv. Official methodologies for measuring total phosphorus content do not account for the wide variation in seafood mineral composition due to various factors;
xv. Interferences in analytical methodologies for measuring phosphorus content in seafood may compromise measured values, leading to overestimation;
xvi. Limited scientific studies in national and international literature exclusively address phosphorus quantification in fresh or frozen seafood;
xvii. The absence of limiting determinations for total phosphorus in raw seafood, as seen in major regulatory bodies, raises challenges in setting universal phosphorus limits;
xviii. Phosphate use can increase the sodium content of treated seafood, posing challenges in reducing salt intake associated with seafood consumption;
xix. Cooperation and common sense are crucial for successful collaboration between industry and regulatory bodies on physical-chemical parameters in seafood;
xx. Insufficient data on food composition and use can lead to incorrect research results, incorrect policy decisions, misleading food labels, false health claims, and inappropriate food choices;
xxi. The technical inability to set a cut-off point, such as a phosphorus or sodium limit for any species of seafood, is evident;
xxii. Sodium content limitation by Brazilian authorities pose challenges for both federal agricultural inspectors and entrepreneurs in compliance; and
xxiii. Exceeding phosphorus or sodium limits set by Brazilian authorities may not necessarily harm health, as many foods in the market surpass recommended limits without being removed or prohibited.

Conclusion

Food-grade phosphates are fundamental to maintaining the technological, sensory, and nutritional quality of seafood products. Their ability to enhance water-holding capacity, texture, and yield provides significant economic and technological benefits to the seafood industry. However, excessive or improper application may compromise product integrity, alter sensory attributes, and lead to economic or regulatory noncompliance.

The studies reviewed demonstrate that the functional benefits of phosphates are closely linked to their chemical structure, concentration, treatment time, and seafood species. The use of blends has proven particularly effective for improving yield and maintaining desirable sensory attributes, as shown in experimental data from fish, shrimp, and mollusk species.

Despite their recognized technological advantages, phosphate use continues to present analytical and regulatory challenges. Variability in natural phosphorus content, limited sensitivity of detection methods, and the absence of harmonized international limits hinder consistent monitoring. Thus, analytical standardization, validation of phosphate-specific methods, and the integration of chemical, sensory, and physicochemical indicators are priorities for reliable quality control.

Moreover, while phosphates are not directly associated with significant toxicological risks when used within established limits, attention must be paid to total dietary intake and environmental sustainability. Future research should focus on understanding phosphate-protein interactions, developing phosphate alternatives with lower environmental impact, and harmonizing global legislation to ensure fair trade, consumer transparency, and food integrity.

In summary, the sustainable and scientifically grounded use of food-grade phosphates, underpinned by accurate analytical tools and balanced regulation, remains essential for maintaining seafood quality, consumer trust, and the long-term sustainability of the seafood industry.

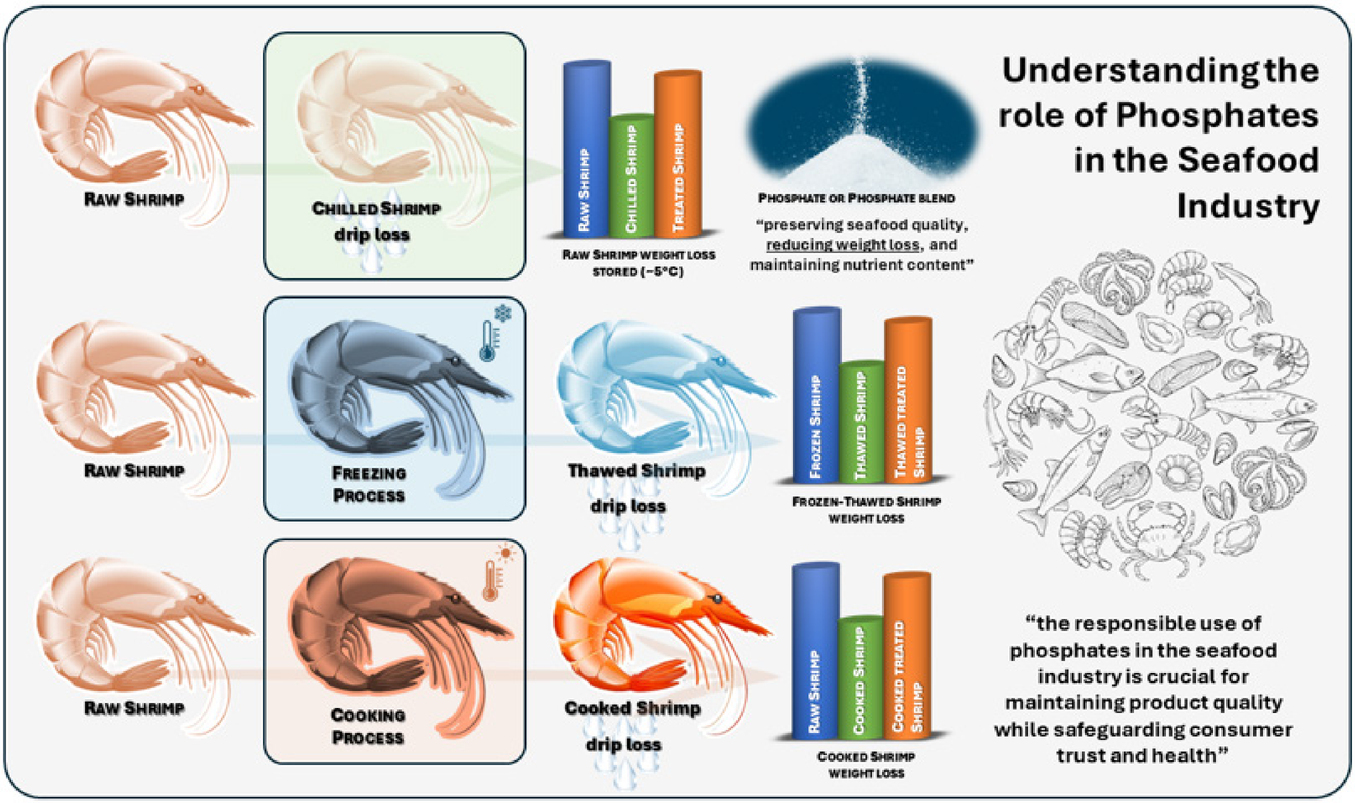
Acknowledgements

None.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Appendix A



Graphical abstract that summarizes the topic addressed in the article in a simple and objective way.

References

1. Petricorena ZC. Chemical composition of fish and fishery products. In: Cheung PCK, Mehta BM, editor. *Handbook of Food Chemistry*. 2015:403–435.
2. Venugopal V. Nutrients and nutraceuticals from seafood. In: Mérillon JM, Ramawat KG, editors. *Bioactive Molecules in Food*. 2019:1397–1440.
3. Aakre I, Bøkevoll A, Chaira J, et al. Variation in nutrient composition of seafood from Northwest Africa: implications for food and nutrition security. *Foods.* 2020;9(10):1516.
4. Durazzo A, Di Lena G, Gabrielli P, et al. Nutrients and bioactive compounds in seafood: quantitative literature research analysis. *Fishes*. 2022;7:132.
5. Alasalvar C, Taylor KDA, Zubcov E, et al. Differentiation of cultured and wild sea bass (Dicentrarchus labrax): total lipid content, fatty acid, and trace mineral composition. *Food Chem*. 2002;79(2):145–150.
6. Ahmed I, Jan K, Fatma S, et al. Muscle proximate composition of various food fish species and their nutritional significance: a review. *J Anim Physiol Anim Nutr*. 2022;106(3):690–719.
7. Rodrigues MJ, Franco F, Martinho F, et al. Essential mineral content variations in commercial marine species induced by ecological and taxonomical attributes. *J Food Compos Anal*. 2021;103:104118.
8. Mogobe O, Mosepele K, Masamba WR. Essential mineral content of common fish species in Chanoga, Okavango Delta, Botswana. *Afr J Food Sci.* 2015;9(9):480–486.
9. El–Faer MZ, Rawdah TN, Attar KMet al. Mineral and proximate composition of some commercially important fish of the Arabian Gulf. *Food Chem*. 1992;45(2):95–98.
10. Gill T. Nucleotide–degrading enzymes. In: Haard NF, Simpson BK, editor. *Seafood Enzymes: Utilization and Influence on Postharvest Seafood Quality*. New York, NY: Marcel Dekker; 2000:37–68.
11. Karakoltsidis PA, Zotos A, Constantinides SM. Composition of the commercially important Mediterranean fin fish, crustaceans, and mollusks. *J Food Compos Anal*. 1995;8(3):258–273.
12. Watabe S, Kamal M, Hashimoto K. Postmortem changes in ATP, creatine phosphate, and lactate in sardine muscle. *J Food Sci*. 1991;56(1):151–153.
13. Hong H, Regenstein JM, Luo Y. Importance of ATP–related compounds for freshness and flavor of postmortem fish and shellfish muscle: a review. *Crit Rev Food Sci Nutr*. 2017;57(9):1787–1798.
14. Prabhakar PK, Vatsa S, Srivastav PP, et al. A comprehensive review on freshness of fish and assessment methods. *Food Res Int*. 2020;133:109157.
15. Ginson J, Kumari KRR, Bindu J. Review on spoilage and quality indices of prawns. *Fish Technol.* 2021;58:191–202.
16. Seafish. Review of Polyphosphates as additives and testing methods for them in scallops and prawns. Campden BRI Report SR654; 2012. *Accessed December* 11, 2023.
17. Tavares M, Gonçalves AA. *Aspectos físico–químicos do pescado.* In: Gonçalves AA, editor. *Tecnologia do Pescado. 2nd ed*. 2021:10–17.
18. Gonçalves AA. Phosphates for seafood processing. In: Akita D, Iwate C, editor. Phosphates: Sources, Properties and Applications. 2012:83–112.
19. *Boiţeanu CN, Neacsu F. Phosphorus content in pikeperch fillets sold on the European market. Sci Works C Vet Med*. 2021;68(1):141–147.
20. Calvo MS, Dunford EK, Uribarri J. Industrial use of phosphate food additives and cardiorenal disease risk. *Nutrients*. 2023;15(16):3510.

21. Thórarinsdóttir KA, Arason S, Thorkelsson G. The Role and fate of added phosphates in salted cod Products. report 27–10. Reykjavík, Iceland: *Matís Icelandic Food and Biotech R&D;* 2010:1–33.

22. Gao R, Yuan L, Yu G. An innovative method for polyphosphate determination in aquatic products with interdiction of polyphosphate hydrolysis using ion chromatography. *Adv Mater Res*. 2012;538–541:2334–2337.

23. Li H, Fu F, Yang W, et al. A simple fluorescent probe for fast and sensitive detection of inorganic phosphate based on uranine@ZIF–8 composite. *Sens Actuators B Chem*. 2019;301:127110.

24. Panseri S, Arioli F, Biolatti C, et al. Detection of polyphosphates in seafood and its relevance toward food safety. *Food Chem*. 2020;332:127397.

25. Ünal SB, Erdogdu F, Ekiz HI, et al. Experimental theory, fundamentals, and mathematical evaluation of phosphate diffusion in meats. *J Food Eng*. 2004;65(2):263–272.

26. Watanabe MT, Araujo RM, Vogt BP, et al. Most consumed processed foods by patients on hemodialysis: alert for phosphate–containing additives and the phosphate–to–protein ratio. *Clin Nutr ESPEN*. 2016;14:37–41.

27. Abbas KA, Mohamed A, Jamilah B, et al. Correlations between fish freshness and pH during cold storage: a review. *Am J Biochem Biotechnol.* 2008;4(4):416–421.

28. Todd AM. Utilizing near–infrared spectroscopy to detect sodium tripolyphosphate in treated penaeus aztecus and Penaeus setiferus shrimp. Master's thesis. Baton Rouge, LA: *Louisiana State University; 2011. Accessed* May 4, 2024.

29. Gonçalves S, Alves VR, Perez SO, et al. Rapid method for the determination of citrate, phosphate, and sulfite in seafood by capillary zone electrophoresis. *Food Chem.* 2020;321:126705.

30. Gonçalves AA. Tecnologia do Pescado: Ciência, Tecnologia, Inovação e Legislação. 2nd ed. Rio de Janeiro, Brazil: *Atheneu*; 2021.

31. Contreras–Guzmán ES. Bioquímica de Pescados e Derivados. *Jaboticabal, Brazil:* FUNEP; 1994.

32. Gonçalves AA, Ribeiro JLD. Effects of phosphate treatment on quality of red shrimp (Pleoticus muelleri) processed with cryomechanical freezing. *LWT Food Sci Technol*. 2009;48(8):1435–1438.

33. Lemos LLA, Gonçalves AA. Can pH and water–to–protein ratio be good instruments to evaluate abusive water addition in seafood by phosphate addition? *J Aquat Food Prod Technol*. 2019;28(3):298–313.

34. Lampila LE. Functions and uses of phosphates in the seafood industry. *J Aquat Food Prod Technol*. 1992;1(3–4):29–41

35. Lampila LE. Polyphosphates: rationale for use and functionality in seafood and seafood products. In: *Proceedings of the 18th Annual Tropical and Subtropical Fisheries Technological Conference of the Americas*; 1993; Virginia, USA:13–20.

36. Henson LS, Kowalewski KM. Use of phosphates in seafood. *Infofish Int*. 1992;5:52–54.

37. Aitken A. Polyphosphates in Fish Processing. Torry Advisory Note No. 31. Aberdeen, UK: Torry Research Station; 2001:1–4. *Accessed December* 11, 2023.

38. Gonçalves AA, Ribeiro JLD. Do phosphates improve seafood quality? Reality and legislation. *Pan–Am J Aquat Sci.* 2008;3(3):237–247.

39. Kim JS, Schnee R, Park JW. Chemical and functional properties of various blends of phosphates. *J Food Qual.* 2009;32(4):504–521.

40. Damasceno MSP, Gonçalves AA. Effect of food–grade phosphate pretreatment prior to industrial cooking on the quality of cooked peeled shrimp (*Litopenaeus vannamei*). *J Sci Food Agric*. 2019;99(7):3299–3306.

41. Oliveira MES, Gonçalves AA. Effect of different food–grade additives on the quality of Pacific white shrimp (*Litopenaeus vannamei*) after two freeze–thaw cycles. *LWT Food Sci Technol.* 2019;113:108301.

42. Brazil. Ministério da Saúde; Agência Nacional de Vigilância Sanitária (ANVISA). Instrução Normativa nº 380, de 3 de julho de 2025, que altera a Instrução Normativa nº 211, de 1º de março de 2023. *Diário Oficial da União*. July 3, 2025;125(Section 1):333.

43. U.S. Food and Drug Administration. Code of Federal Regulations. Title 21—Food and Drugs. Part 182—Substances Generally Recognized as Safe. Revised November 21, 2023. Accessed December 11, 2023.

44. Gonçalves AA, Ribeiro JLD. Optimization of the freezing process of red shrimp (Pleoticus muelleri) previously treated with phosphates. *Int J Refrig*. 2008;31(7):1134–1144.

45. Gonçalves AA, Rech BT, Rodrigues PM, et al. Quality evaluation of frozen seafood previously treated with phosphates. *Pan–Am J Aquat Sci*. 2008;3(3):248–258.

46. Gonçalves AA, Souza MA, Regis RCP. Effects of different levels of food additives on weight gain and cook–related yield loss of Nile tilapia fillets (*Oreochromis niloticus*). *Int Food Res J*. 2018;25(5):2068–2080.

47. Codex Alimentarius Commission. General Standard for Food Additives. Food Category 09.0—Fish and Fish Products. CODEX STAN 192–1995. Revision 2023. *Rome, Italy*: FAO/WHO; 2023.

48. Chan SS, Roth B, Jessen F, et al. Water–holding properties of Atlantic salmon. *Compr Rev Food Sci Food Saf.* 2022;21(1):477–498.

49. Chan SS, Roth B, Skare M, et al. Effect of chilling technologies on water–holding properties and quality throughout the value chain of Atlantic salmon (*Salmo salar*). *Aquaculture.* 2020;526:735381.

50. Goes ESR, Lara JAF, Gasparino E, et al. Pre–slaughter stress affects ryanodine receptor gene expression and water–holding capacity in Nile tilapia fillets. *PLoS One*. 2015;10(6):e0129145.

51. Kudryashov LS, Kudryashova OA. Water–holding and water–holding capacity of meat and methods of determination. *Theory Pract Meat Process*. 2023;8(1):62–70.

52. Turan H, Kaya Y, Erkoyuncu I. Effects of glazing, packaging, and phosphate treatments on drip loss in rainbow trout (Oncorhynchus mykiss) during frozen storage. *Turk J Fish Aquat Sci*. 2003;3(2):105–109.

53. Erdogdu F, Balaban MO, Otwell WSE, et al. Cook–related yield loss of Pacific white shrimp (*Penaeus vannamei*) treated with phosphates. *J Food Eng*. 2004;64(3):297–300.

54. Skipnes D, Østby ML, Hendrickx ME. Characterization of cook loss and water–holding capacity in heat–treated cod (*Gadus morhua*) muscle. *J Food Eng*. 2007;80(4):1078–1085.

55. Carneiro CS, Mársico ET, Ribeiro ROR, et al. Quality attributes of shrimp treated with polyphosphate after thawing and cooking assessed by physicochemical methods and low–field ^{1}H NMR. *J Food Process Eng.* 2013;36(4):492–499.

56. Carneiro CS, Mársico ET, Ribeiro ROR, et al. Effect of sodium tripolyphosphate on frozen shrimp evaluated by physicochemical methods and low–field nuclear magnetic resonance. *LWT Food Sci Technol.* 2013;50(2):401–407.

57. Chen KY. Study of polyphosphate metabolism in intact cells by ^{31}P nuclear magnetic resonance spectroscopy. In: Schröder HC, Müller WEG, editor. *Prog Mol Subcell.* 1999;23:253–273.

58. Seafish. Food Additives and Their Use in Seafood: Industry Guidance Note—Legislation. FS61–0211. Grimsby, UK: Seafish; 2011. Accessed December 11, 2023.

59. Long NHBS, Gál R, Búnka F. Use of phosphates in meat products. *Afr J Biotechnol*. 2011;10(86):19874–19882.
60. Molina RE, Bohrer BM, Vásquez Mejia SM. Phosphate alternatives for meat processing and challenges for the industry: a critical review. *Food Res Int*. 2023;166:112624.
61. Thórarinsdóttir KA, Gudmundsdottir G, Arason S, et al. Effects of salt, phosphates, and proteins on physicochemical characteristics of frozen cod (Gadus morhua) fillets. *J Food Sci*. 2004;69(4):144–152.
62. Nguyen MV, Arason S, Thorkelsson G, et al. Effects of added phosphates on lipid stability during salt curing and rehydration of cod (Gadus morhua). *J Am Oil Chem Soc*. 2013;90(3):317–326.
63. Wangtueai S, Tongsiri S, Maneerote JE, et al. Effect of phosphate on frozen Nile tilapia fillets. *Food Appl Biosci J*. 2014;2:203–215.
64. Crawford DL. Meat Yield and Shell Removal Functions of Shrimp Processing. Special Report 597. Corvallis, OR: Oregon State University Extension Marine Advisory Program; 1980. Accessed December 11, 2023.
65. Chao X, Bin Z, Lu–Kai M, et al. Cryoprotective effects of trehalose, alginate, and alginate oligosaccharides on cooked shrimp during frozen storage. *J Food Process Preserv*. 2017;41(2):e12825.
66. Ying X, Wu Q, Shui S, et al. Comparison of sodium tripolyphosphate and sodium trimetaphosphate pretreatments in whiteleg shrimp during frozen storage. *Food Chem*. 2021;348:129134.
67. English MM, Keough JM, McSweeney MB, et al. Impact of a novel cryoprotectant blend on sensory quality of frozen lobster (*Homarus americanus*). *J Food Sci*. 2019;84(6):1547–1553.
68. Ngoc TTA, Sarnes R, Binh LN. Optimization of soaking treatment on Pangasius fillet quality. *Food Res*. 2020;4(Suppl 6):79–84.
69. Zhi–Hui J, Zhi–Han G, Wei W, et al. Effect of compound phosphate on water–holding capacity and nutritional quality of sea bass fillets. *J Food Process Preserv.* 2022;46(6):e16511
70. Wangtueai S, Maneerote J, Seesuriyachan P, et al. Combined effects of phosphate and NaCl on quality of frozen Nile tilapia fillets during storage. *Walailak J Sci Technol*. 2020;17(4):313–323.
71. Demayanti R, Anggo AD, Suhaeli FA. Quality of frozen catfish fillets with NaCl and sodium tripolyphosphate. *AIP Conf Proc*. 2023;2586(1):060006.
72. Huang J, Bakry AM, Zeng S, et al. Effect of phosphates on gelling and water mobility of myofibrillar protein from grass carp. *Food Chem*. 2019;272:84–92.
73. Rippen T, Sutton H, Lacey P, et al. Functional, microbiological, and sensory changes in sea scallops treated with sodium tripolyphosphate. In: Proceedings of the 18th Annual Tropical and Subtropical Fisheries Technological *Conference of the Americas*; 1993; Virginia, USA:51–71.
74. Etemadian Y, Shabanpour B, Mahoonak ARS, et al. Cryoprotective effects of polyphosphates on Rutilus frisii kutum fillets during ice storage. *Food Chem*. 2011;129(4):1544–1551.
75. Crapo CA, Crawford DL. Influence of polyphosphate soak and cooking procedure on yield and quality of Dungeness crab meat. *J Food Sci*. 1991;56(3):657–659.
76. Sampaio GR, Lobão VL, Rocco SC. Use of phosphates to reduce exudate and improve sensory attributes of freshwater shrimp (Macrobrachium rosenbergii). *Bol Inst Pesca*. 2001;27(1):97–107.
77. Calder BL. *Use of Polyphosphates to Maintain Yield and Quality of Cryogenically Frozen Lobster and Crab*. Doctoral dissertation. Orono, ME: University of Maine; 2003. Accessed May 4, 2024.
78. Thanonkaew A, Benjakul S, Visessanguan W, et al. Effect of antioxidants on quality changes of cuttlefish muscle during frozen storage. *LWT Food Sci Technol*. 2008;41(1):161–169.
79. Teixeira AM, Beirão LH. Effects of cryoprotective agents on water–holding capacity of fish paste using response surface analysis. *Bol CEPPA*. 1999;17(1):71–82.
80. Julavittayanukul O, Benjakul S, Visessanguan W. Effect of phosphate compounds on gel–forming ability of surimi from bigeye snapper (*Priacanthus tayenus*). *Food Hydrocoll*. 2006;20(8):1153–1163.
81. Faithong J, Raksakulthai N, Chaiyawat M. Effect of phosphates and salt on yield and quality of cooked white shrimp (*Penaeus vannamei)*. *Kasetsart J Nat Sci*. 2006;40(Suppl):108–116.
82. Suyani NK, Rathore SS, Vandarwala UG, et al. Physical, chemical, and sensory quality evaluation of phosphate–treated and non–treated PUD shrimp (*Litopenaeus vannamei*). *Int J Fish Aquat Stud.* 2019;7(5):296–299.
83. Ying XG, Wu QJ, Shui SS, et al. Insights into similarities and differences of whiteleg shrimp pre–soaked with sodium tripolyphosphate and sodium trimetaphosphate during frozen storage. *Food Chem*. 2021;348:129134.
84. Kingswacharapong P. *Effect of Treatments Using Some Additives on Yield and Characteristics of Pacific White Shrimp*. Master's thesis. Hat Yai, Thailand: Prince of Songkla University; 2015. Accessed December 11, 2023.
85. Kingwascharapong P, Benjakul S. Effect of phosphate and bicarbonate replacers on quality changes of raw and cooked Pacific white shrimp during repeated freeze–thawing. *Int J Refrig*. 2016;67:345–354.
86. Kingwascharapong P, Benjakul S. Effect of strong alkaline solutions on yield and characteristics of Pacific white shrimp (*Litopenaeus vannamei*). *Int Food Res J*. 2016;23(3):1136–1144.
87. Nor Salasiah M, Jirarat T. Effect of food additives on quality of white shrimp (*Litopenaeus vannamei*). *Food Res.* 2018;2(6):546–554.
88. Chantarasataporn P, Yoksan R, Visessanguan W, et al. Water–based nano–sized chitin and chitosan as seafood additives: a case study of Pacific white shrimp (*Litopenaeus vannamei*). *Food Hydrocoll*. 2013;32(2):341–348.
89. Masniyom P, Benjakul S, Visessanguan W. Combination effects of phosphate and modified atmosphere on quality and shelf–life of refrigerated seabass slices. *LWT Food Sci Technol.* 2005;38(7):745–756.
90. Gonçalves AA. *Estudo do Processo de Congelamento do Camarão Associado ao Uso do Aditivo Fosfato. Doctoral dissertation. Porto Alegre*, Brazil: Universidade Federal do Rio Grande do Sul; 2005.
91. Barros JR, Gonçalves AA, Pereira CS, et al. Influence of sodium tripolyphosphate on water–holding capacity of marinated croaker fillets after thawing. In: *Proceedings of the IV Congresso Brasileiro de Ciência e Tecnologia de Carnes*; 2007; Campinas, Brazil:177–179.
92. Anghileri LJ, Miller ES. Hydrolysis of sodium polyphosphates. *Z Naturforsch B*. 1971;26(6):543–545.
93. Brazil. Ministério da Agricultura, Pecuária e abastecimento. *instrução normativa nº 21, de 31 de maio de 2017*. Regulamento técnico para peixe congelado. *Diário Oficial da União*. May 31, 2017;108(Section 1):5–6.
94. Brazil. Ministério da Agricultura e do Abastecimento. *Instrução Normativa nº 23, de 20 de agosto de 2019*. Regulamento técnico para camarão fresco, resfriado, congelado, descongelado, parcialmente cozido e cozido. *Diário Oficial da União*. August 20, 2019;166(Section 1):1.
95. Brazil. Ministério da Agricultura e do Abastecimento. *Instrução Normativa nº 24, de 20 de agosto de 2019*. Regulamento técnico para lagosta fresca e congelada. *Diário Oficial da União*. August 20, 2019;166(Section 1):4.
96. Brazil. Ministério da Agricultura e do Abastecimento. *Portaria SDA nº 1.022, de 29 de fevereiro de 2024*. Regulamento técnico de identidade e qualidade de moluscos cefalópodes. *Diário Oficial da União*. February 29, 2024;43(Section 1):6.

97. Health Canada. *List of Permitted Food Additives with Other Accepted Uses*. 2023. Accessed December 11, 2023.

98. Codex Alimentarius Commission. Standard for Quick Frozen Fish Fillets. CODEX STAN 190–1995. Revised 2017. Rome, Italy: *FAO/WHO*. Accessed December 11, 2023.

99. Teixeira B, Vieira H, Lourenço H, et al. Control of phosphate levels in seafood from the Portuguese market. *J Food Compos Anal*. 2017;62:94–102.

100. Calvo MS, Tucker KL. Is phosphorus intake exceeding requirements a risk factor for bone health? Ann N Y *Acad Sci*. 2013;1301(1):29–35.

101. Calvo MS, Moshfegh AJ, Tucker KL. Assessing health impacts of phosphorus in the food supply. *Adv Nutr*. 2014;5(1):104–113.

102. Vasquez Mejia SM, Francisco A, Manique Barreto PL, et al. Incorporation of β–glucans in meat emulsions using optimal mixture modeling. *Meat Sci.* 2018;143:210–218.

103. Huang S, Roman S, Martinez MM, et al. Effect of extruded breadfruit flour on physicochemical properties of beef emulsion systems. *Meat Sci*. 2021;172:108370.

104. Gonçalves AA. The pH of seafood meat: a problem that deserves clarification. *MOJ Food Process Technol.* 2017;4(1):00081.

105. Van Ruth SM, Brouwer E, Koot A, et al. Seafood and water management. *Foods*. 2014;3(4):622–631.

106. Biesalski HK, Grimm P. Nutrição: Texto e Atlas. Porto Alegre, Brazil: *Artmed;* 2007.

107. Yoza N, Akazaki I, Nakazato T, et al. HPLC determination of pyrophosphate in the presence of excess orthophosphate. *Anal Biochem*. 1991;199(2):279–285.

108. Sutton AH. Hydrolysis of sodium triphosphate in cod and beef muscle. *J Food Technol*. 1973;8(2):185–195.

109. Tenhet V, Finne G, Nickelson R, et al. Phosphorus levels in shrimp treated with sodium tripolyphosphate. *J Food Sci*. 1981;46(2):350–356.

110. Heitkemper DT, Kaine LA, Jackson DS, Wolnik KA. Determination of tripolyphosphate and hydrolysis products in processed shrimp. In: *Proceedings of the 18th Annual Tropical and Subtropical Fisheries Technological Conference of the Americas*; 1993; Virginia, USA:92–100.

111. Kaufmann A, Maden K, Leisser W, et al. Analysis of polyphosphates in fish and shrimp tissues by ion chromatography. *Food Addit Contam*. 2005;22(11):1073–1082.

112. World Health Organization. *Reducing Salt Intake in Populations: Report of a WHO Forum and Technical Meeting*. Paris, France; October 5–7, 2006. Geneva, Switzerland: WHO; 2006. Accessed December 11, 2023.

113. Brazil. Ministério da Saúde; Agência Nacional de Vigilância Sanitária. *Teor de Sódio nos Alimentos Processados. Informe Técnico* No. 69. Brasília, Brazil; 2015.

114. Roe M, Church S, Pinchen H, et al. *Nutrient Analysis of Fish and Fish Products: Analytical Report*. Norwich, UK: Institute of Food Research; 2013. Accessed December 11, 2023.

115. AOAC International. Fish and other marine products. AOAC Official Method 937.07. In: Latimer GW Jr, ed. *Official Methods of Analysis of AOAC International*. 22nd ed. New York, NY: AOAC; 2023.

116. Brazil. Ministério da Agricultura, Pecuária e Abastecimento. *Manual de Métodos Oficiais para Análise de Alimentos de Origem Animal*. Brasília, Brazil: MAPA; 2022.

117. He Y, Dai L, Hu L, et al. Ratiometric fluorescent detection of total phosphates in frozen shrimp using Zr(IV)–modified gold nanoclusters. *Food Chem*. 2023;426:136564.

118. EFSA Panel on Food Additives. Re–evaluation of phosphoric acid and phosphates as food additives. *EFSA J*. 2019;17(6):5674.

119. Jastrzębska A, Szlyk E. Application of ^{31}P NMR for determination of added polyphosphate in pork meat. *Chem Pap*. 2009;63(4):414–419.

120. Gibson DM, Murray CK. Polyphosphates and fish: chemical studies. *J Food Technol*. 1973;8(2):197–204.

121. Instituto Adolfo Lutz. *Normas Analíticas do Instituto Adolfo Lutz: Métodos Físico–Químicos para Análise de Alimentos*. Zenebon O, Pascuet NS, Tiglea P, coords. São Paulo, Brazil: Instituto Adolfo Lutz; 2008:1020 p.

122. Murray J, Burt JR. The Composition of Fish. Torry Advisory Note No. 38. Aberdeen, UK: *Torry Research Station*; 2001:14 p.

123. Greenfield H, Southgate DAT. *Food Composition Data: Production, Management and Use*. 2nd ed. New York, NY: Springer; 2003.

124. Iammarino M, Di Taranto A. Determination of polyphosphates in products of animal origin using validated ion chromatography. *Eur Food Res Technol.* 2012;235:409–417.

125. Mashhadi Farahani S, Dadmehr M, Ali Karimi M, et al. Fluorometric detection of phytase activity and phosphate ions using gelatin–supported silver nanoclusters. *Food Chem*. 2022;396:133711.

126. Ramakrishnam Raju MV, Harris SM, Pierre VC. Design and applications of metal–based molecular receptors and probes for inorganic phosphate. *Chem Soc Rev*. 2020;49(4):1090–1108.

127. FAO/INFOODS. Food composition challenges. *International network of food data systems*; 2022. Last updated october 20, 2022. Accessed December 11, 2023.

128. Food and Agriculture Organization of the United Nations. *FAO/INFOODS Global Food Composition Database for Fish and Shellfish (uFiSh1.0)*. Rome, Italy: FAO; 2023.

129. Ritz E, Hahn K, Ketteler M, et al. Phosphate additives in food-a health risk. *Dtsch Arztebl Int*. 2012;109(4):49–55.

130. Uribarri J. Phosphorus homeostasis in normal health and chronic kidney disease. *Semin Dial*. 2007;20:295–301.

131. EFSA panel on food additives. Assessment of a published review on health risks associated with phosphate additives in food. *EFSA J*. 2013;11(11):3444.

132. Scientific Committee for Food. *Nutrient and Energy Intakes for the European Community.* Opinion expressed December 11, 1992. Brussels, Belgium: European Commission; 1992. Accessed December 11, 2023.

133. EFSA Panel on dietetic products, nutrition and allergies. Opinion of the scientific panel on dietetic products, nutrition and allergies on a request from the commission related to the tolerable upper intake level of phosphorus. *EFSA Journal*. 2005;233:1-19.

134. Joint FAO/WHO Expert committee on food additives. *Evaluation of the toxicity of a number of antimicrobials and antioxidants. sixth report.* FAO nutrition meetings report series no. 31. rome, italy: fao; 1962.

135. Joint FAO/WHO Expert committee on food additives. *Specifications for the identity and purity of food additives and their toxicological evaluation: Emulsifiers, stabilizers, bleaching and maturing agents.* seventh report. FAO nutrition meetings series No. 35. Rome, Italy: FAO; 1964.

136. Joint FAO/WHO Expert committee on food additives. *Specifications for the identity and purity of food additives and their toxicological evaluation: Food colours and some antimicrobials and antioxidants*. Eighth report. FAO nutrition meetings series no. 38. rome, italy: FAO; 1965.

137. Joint FAO/WHO Expert Committee on Food Additives. *Specifications for the Identity and Purity of Food Additives and Their Toxicological Evaluation: Some Antimicrobials, Antioxidants, Emulsifiers, Stabilizers, Flour Treatment Agents, Acids, and Bases*. Ninth Report. FAO Nutrition Meetings Series No. 40. Rome, Italy: FAO; 1966.

138. Joint FAO/WHO expert committee on food additives. *Specifications for the Identity and Purity of Food Additives and Their Toxicological Evaluation: Some Food Colours, Emulsifiers, Stabilizers, Anticaking agents,* and other substances. thirteenth report. FAO nutrition meetings series No. 46. Rome, Italy: FAO; 1970.

139. Joint FAO/WHO expert committee on food additives. *Evaluation of food additives: specifications for Identity and purity and toxicological evaluation.* Fourteenth Report. FAO nutrition meetings series No. 48. Rome, Italy: FAO; 1971.

140. Joint FAO/WHO expert committee on food additives. *Toxicological Evaluation of Certain Food Additives*. Seventeenth Report. FAO Nutrition meetings series No. 53. Rome, Italy: FAO; 1974.

141. Joint FAO/WHO Expert committee on food additives. *Evaluation of certain food additives and contaminants*. Twenty–sixth report. WHO technical report series No. 683. Geneva, Switzerland: WHO; 1982.

142. Joint FAO/WHO Expert committee on food additives. *Evaluation of certain food additives and contaminants*. Fifty–seventh report. WHO technical report series No. 909. Geneva, Switzerland: WHO; 2002.

143. Scientific committee for food. *Report on Provisions Relating to Additives and Processing Aids in Fine Bakers' Wares*. Opinion expressed May 1, 1978. Brussels, belgium: European commission; 1978. Accessed December 11, 2023.

144. Scientific committee for food. *Essential requirements of infant formulae and follow–up milks based on Cow's milk proteins*. opinion expressed april 27, 1983. Brussels, belgium: European commission; 1983. accessed december 11, 2023.

145. Scientific committee for food. *First series of food additives of various technological functions.* opinion expressed May 18, 1990. Brussels, belgium: European commission; 1990. Accessed December 11, 2023.

146. Calvo MS, Sherman RA, Uribarri J. Dietary phosphate and the forgotten kidney patient: need for FDA regulatory action. *Am J Kidney Dis*. 2019;73(4):542–551.

147. Lee S, Jo K, Jeong SK, et al. Recent strategies for improving meat product quality. *J Anim Sci Technol*. 2023;65(5):895–911.