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Chemical Intervention Technologies for Seafood Safety

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ABSTRACT

The escalating global demand for premium seafood products and the concurrent increase in foodborne illnesses have spurred the development of innovative and environmentally sustainable preservation methodologies. Contemporary intervention technologies, endorsed by governmental agencies and subject to stringent regulations within the food industry, encompass chlorine-based sanitizers, electrolyzed oxidizing water, ozone, and lactic acid. The inherent fragility of seafood presents formidable technological hurdles, given its susceptibility to modifications during conventional processing. Consequently, a synergistic amalgamation of diverse techniques to create a hurdle effect emerges as a promising approach for achieving superior microbiological standards in seafood, while preserving its desirable organoleptic attributes. This review comprehensively elucidates the underlying principles of various chemical interventions employed for the eradication of pathogens and spoilage microorganisms in seafood. The analysis encompasses an assessment of their advantages, limitations, and potential applicability in industrial settings.

Key words : chemical intervention technologies, preservation, seafood, pathogenic bacteria

Ⅰ. Introduction

The escalating global demand for seafood products in recent years has been accompanied by a growing imperative to ensure the safety and quality of these consumables. As the annual per capita consumption of seafood has more than doubled over the past half-century, reaching over 20 kg in 2014 (1), concerns about foodborne illnesses associated with seafood have garnered increased attention. Among the numerous challenges in seafood safety, microbial pathogens stand out as significant contributors to foodborne outbreaks. This necessitates a comprehensive exploration of effective chemical intervention technologies designed to eliminate pathogenic bacteria in seafood products, thereby enhancing their microbiological standards and overall quality.

One of the conventional approaches to microbial control in the food processing industry has been the use of chlorine-based sanitizers. Chlorine, owing to its wide availability, low cost, and bactericidal properties, has been a staple in sanitization practices (2). However, its drawbacks, including corrosiveness and limited effectiveness against certain microorganisms, have spurred investigations into alternative agents. This introduction delves into the multifaceted landscape of chemical interventions, beginning with the prevalent use of chlorine-based sanitizers, and navigates through emerging technologies such as electrolyzed oxidizing water, ozone, and lactic acid. Each of these chemical agents is scrutinized for its antimicrobial efficacy, environmental impact, and potential to enhance the overall safety and sensory quality of seafood products.

As the delicate nature of seafood poses unique challenges in processing, the exploration of synergistic combinations of chemical interventions becomes paramount. The intricate interplay between these technologies offers a glimpse into a future where seafood processing can achieve superior microbiological standards while preserving the organoleptic properties that define the appeal of these products. This introduction sets the stage for a comprehensive review of the principles, benefits, limitations, and potential industrial applications of chemical intervention technologies aimed at ensuring the safety and quality of seafood products in a dynamically evolving global food landscape.

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Ⅱ. Chemical Intervention Technologies

1. Chlorine-based sanitizer

Chlorine solution has been the most commonly used conventional disinfectants in the food processing industry. This is due to its wide availability, low cost, bactericidal effect and that it is easy to monitor the free residual level on food samples and food processing facilities (2, 3). The Food and Agriculture Organization (FAO) reported that up to 200 ppm chlorine is used for sanitizing clean food processing equipment and 0.2∼0.5 ppm free residual chlorine level should be maintained in the distribution system (3). Despite its antimicrobial properties, chlorine suffers many limitations which include its corrosiveness to the products and processing equipment, low effectiveness against bacterial spores and protozoan oocysts, rapid decrease in bactericidal effect upon contact with organic matter and increased temperature, as well as the production of carcinogenic and teratogenic by-products such as trihalomethanes and haloacetic acids in water (2, 4-6). Due to this concern, other chlorine-based sanitizers, such as chlorine dioxide, were being studied as an alternative sanitizing agent in seafood processing. Chlorine dioxide is more stable than chlorine and possesses higher antimicrobial activity than chlorine. Studies have illustrated the effectiveness of chlorine dioxide in the depuration of *V. parahaemolyticus* in oyster and reduction of microorganisms in water for seafood washing and handling (7). Nevertheless, chlorine dioxide treatments decreased the sensorial properties of seafood and its by-products, such as chlorite and chlorate, continue to be a health concern (7). These factors fuelled the research in non-chlorine based sanitizers which are safe, environmental friendly and able improve the overall microbial and sensorial quality of seafood products.

2. Electrolyzed oxidizing (EO) water

The use of electrolysed oxidising (EO) water began in Japan and has been reported to possess strong antimicrobial effects on a variety of pathogenic bacteria related to food safety (8). EO water is produced by the electrolysis of a dilute (0.1∼0.2%) sodium chloride (NaCl) solution (9). Hypochlorous acid (HOCl) is formed at the anode during electrolysis results in a low pH solution called acidic electrolyzed water (AcEW) with antimicrobial property. The bactericidal of AcEW against pathogens and spoilage microorganisms is stronger than that of conventional chlorine-based sanitizers due to its high oxidation reduction potential (>1,000 mV) at low pH (10∼12). The cathode, on the other hand, produces hydroxyl ions, resulting in the formation of basic EO water is used for dirt and grease removal from items such as cutting boards and kitchen utensils (8, 13, 14).

The use of EO water for disinfecting bacteria in raw seafood and seafood processing equipment has been reported (Table 1). Ozer and Demirci (15) showed that treating fresh salmon with acidic EO water, AEW (pH of 2.6, redox potential of 1,150 mV and free chlorine of 90 mg/L) at 35℃ for 64 min resulted in a 1.07 log CFU/g and 1.12 log CFU/g reduction in *E. coli* O157:H7 and *L. monocytogenes*, respectively. Huang and others (14) reported that AEW was effective for reducing 0.7 log CFU/cm^2 of *E. coli* and up to 2.6 log CFU/cm^2 of *V. parahaemolyticus* on tilapia skin surfaces. Another studies indicates that including basic EO water pre-treatment and mild heat increased the antimicrobial activity of AEW against *V. parahaemolyticus* on shrimp by 4.4 log CFU/g (16). In terms of the effect of AEW on the sensory qualities of seafood, Kim et al. (17) reported that preserving Pacific saury with EO ice enhanced the freshness by 4∼5 days as compared to tap water ice.

Apart from the raw seafood commodity, seafood processing equipment could also be contaminated with pathogens such as *L. monocytogenes* due to poor process hygiene by food handlers and cross-contamination with raw seafood and the final products (18). Liu et al. (19) demonstrated that AEW effectively reduced *L. monocytogenes* contamination in seafood processing equipment. In their study, the treatment by immersion in EO water containing 50 mg/L chlorine for 5 min delivered significant reduction of *L. monocytogenes* on stainless steel sheet and ceramic tile (2.33 log CFU) as well as floor tile (1.52 log CFU) when compared to tap water washing. The antimicrobial efficiency of AEW against *L. monocytogenes* was shown to be proportional to its chlorine content and ORP. Another study also investigated the antimicrobial activity of AEW water against *L. monocytogenes* and *Morganella morganii* on seafood processing surfaces which commonly cause listeriosis and histamine fish

Table 1. Selected studies of current chemical intervention technologies in reducing microbial load in seafood

Chemical antimicrobial agent	Target samples/ materials	Target microorganisms	References
Acidic EO water	Seafood processing surface	*L. monocytogenes*	19
	Conveyor belt and raw fish surfaces	*L. monocytogenes* and *Morganella morganii*	20
	Salmon fillet	*Escherichia coli* O157:H7 *L. monocytogenes*	15
	Talapia	*Escherichia coli* *Vibrio parahaemolyticus*	14
Basic EO water and mild heat acidic EO water	Shrimp	*V. parahaemolyticus*	16
Ozonated water (spray)	Salmon fillet	*L. innocua*	25
Ozonated water (Immersion)	Mussels	Aerobic plate count	28
Sterile ozonized water	Hake	Total viable count	29
Lactic acid + chitosan Lactic acid	Shrimps Shrimp	*V. parahaemolyticus* *V. cholera* *V. parahaemolyticus* *S.* Enteriditis *E. coli* O157:H7	30, 34

poisoning respectively (20). AEW achieved a reduction of 7.0 log CFU on the 24-h biofilms of these microorganisms in the MBECTM Assay System. Moreover, the study also revealed strain to strain variability in AEW susceptibility by the fact that not all *L. moncytogenes* strains inoculated on food processing surface were sensitive to AEW. Only three out of ninety *L. monocytogenes* and one out of five strains of *M. morganii* on conveyor belt coupon were reduced by 1∼2.5 log CFU/cm^2 upon treated with EO water for 5 min. *L. monocytogenes* cells attached on raw salmon was also reduced by 2.0 log CFU/g upon exposure to EO water for 5 min. Nevertheless, it was reported that applying AEW on seafood processing equipment might lead to corrosion due to the strong acidity, hence limiting the application (21). The volatile chlorine gas released by AEW at low pH may also cause harm to human and the environment (21).

3. Ozone

Ozone (O_3) is an allotropic form of oxygen (O_2). In 2007, ozone has been approved as GRAS (Generally Recognized as Safe) chemical and FDA in 2001 officially approved ozone-containing chemicals for use in the food industry including seafood (22, 23). According to the United States Occupational Safety and Health Administration (OSHA), the Short Term Exposure Limit (STEL) to ozone is 0.3 ppm for a maximum of 15 min exposure time no more than three times a day (24). Research on ozone has been undergoing as a chlorine-alternative since then for inhibiting spoilage and pathogenic bacteria in seafood processing. Nevertheless, conclusive evidence regarding the sanitizing effect of ozone is insufficient. This is due to process variability in experiments as well as the effect of microbial population, temperature, pH, commodity surface characteristics, and the presence of organic substrates to the antimicrobial effect of ozone (25). Despite the variability, the study of ozone as an antimicrobial agent is still ongoing due to its strong oxidizing power. Ozone gas can be produced by a domestic ozone generator utilising atmospheric air as the oxygen source (23). Aqueous ozone is generated by pulling ozone into a water stream under negative pressure with the aid of an injection system (2, 26). The bactericidal effect of ozone is due to its ability to diffuse through microbes’cell membrane, its high oxidation potential and its reaction with organic material is up to 3,000 times faster than chlorine (27). However, ozone is highly unstable in water and decomposes rapidly to oxygen in which the half-life of ozone activity may be less than 1 min in processing water with suspended organic matter (26). Hence, ozone has to be regenerated during the sanitization process.

Research investigating the efficacy of ozone spray application mechanisms for ensuring microbial safety and chemical quality attributes of high lipid content salmon fillet was carried out by Crowe et al. (25). Their studies indicated that ozone sprays (1.5 mg/L) effectively decreased the initial counts of aerobic bacteria and inoculated *L. innocua* without significantly increased in lipid oxidation levels in salmon fillets stored under 4℃. In another similar study, Vaz-Velho et al. (23) evaluated the efficacy of gaseous ozone (0.1×10^{-3} g/L) and reported a reduction of 1.0 log CFU/g *L. innocua* after 3 week-storage of cold-smoked salmon fillet in vacuum packs at 5℃. Manousaridis et al. (28) immersed mussels in 1.0 mg/L aqueous ozone and discovered significant reductions in aerobic plate count (up to 2.1 log reduction) coupled with a 35% extension in shelf-life of treated mussels. The treatment also did not induce significant changes in lipid oxidation and sensory attributes of treated mussels. Since the application of ozone for direct contact with seafood products has been approved by FDA in 2001, special ozone application practices have been developed. Sterile and ozonized water holds potential in replacing seawater for fresh fish washing and ice manufacturing to conserve the chemical, microbiological and sensorial aspects of fresh fish (29).

4. Lactic acid

Organic acids were found to be effective against psychrophilic and mesophilic microorganisms in fresh produce in the recent years (30, 31). Out of all the organic acids, lactic acid is most commonly used to preserve and disinfect poultry and meat products, but the inhibitory effect of lactic acid on seafood is still under studied (30, 32). Nevertheless, current research suggested that lactic acid is useful for commercial applications for effective decontamination of seafood, such as shrimp (30) and catfish (33). It is found that treatment with 1∼3% lactic acid delivered a *V. parahaemolyticus* reduction of 2∼3 log CFU/g without deteriorating the sensory aspect of the seafood commodity (30, 34).

5. Combination of chemical treatment and irradiation

Synergistic bactericidal effect was observed by Kim et al. (35) when combining irradiation and chlorine treatments in the disinfection of mussel and squids. A combination of 1 kGy gamma radiation and 100 ppm of chlorine further reduced the total aerobic count of mussels by 2.66 log CFU/g and squid by 2.46 log CFU/g as compared to when both treatments were used alone. A higher concentration of chlorine (150 ppm) was required when the radiation source was changed to an electron beam to achieve comparable synergistic effects. This was attributed to the difference in penetration depth and dose rate of the two radiation sources. The same authors also reported enhanced synergistic effects of irradiation and chlorine treatment when 1,000 mg/L of vitamin B_1 was added to the sodium hypochlorite solution. In particular, the addition of thiamine increased the synergistic effect of 2 kGy electron beam radiation combined with 100 ppm chlorine to 2.41 log CFU/g from 0.18 log CFU/g in oysters (36).

Ⅲ. Conclusion

In conclusion, the exploration of chemical intervention technologies for safeguarding seafood products reveals a dynamic landscape of advancements and challenges. The traditional use of chlorine-based sanitizers, despite its widespread adoption, faces limitations such as corrosiveness and environmental concerns. Alternative agents like electrolyzed oxidizing water and ozone showcase promising antimicrobial efficacy, with ongoing research aiming to optimize their application in seafood processing. Lactic acid, recognized for its effectiveness in other domains, emerges as a potential solution for decontaminating seafood, albeit requiring further scrutiny. As the industry seeks environmentally friendly and microbiologically effective alternatives, these chemical interventions offer glimpses into a future where seafood safety can be enhanced while preserving the product's sensory attributes. Continued research and innovation in this domain will play a pivotal role in shaping the landscape of seafood processing, ensuring both consumer health and product quality.

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