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Improving Quality and Shelf Life of Seafood Products Using Plasma Technology

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SUMMARY

This article reviews recent research on the application of nonthermal atmospheric pressure plasma (NTAPP) technology for improving the quality and safety of seafood products. Plasma contains charged particles that can inactivate microorganisms and enzymes without heat damage to quality. Numerous studies show NTAPP effectively reduces spoilage organisms and pathogens on fish, shellfish and their products by 2-4 log units. It inhibits polyphenol oxidase enzymes slowing discoloration in shrimp and shellfish. Plasma also limits protein degradation and textural changes during storage through altering protein confirmation and aggregation. However, its effect on lipid oxidation varies - in some cases increasing and others decreasing oxidation in different seafoods. Optimization of key determinants like treatment time, packaging, product type is needed to control the variable plasma-induced chemical effects. Research gaps exist including demonstrating true shelf-life extension, analyzing specific plasma reactive species and their mechanisms of action, evaluating sensory qualities and consumer acceptance. Overall plasma shows promise for microbial decontamination and quality enhancement in seafood, but scaling up technologies alongside more storage trials, characterization studies, sensory testing is required before commercial adoption. If these challenges are addressed, plasma can enable the next generation of safer, higher quality seafood products.

INTRODUCTION

Seafood products including fish, shellfish and their products are highly perishable commodities owing to their biological composition. The diverse microflora present in freshly harvested seafood, multiply rapidly at ambient storage conditions leading to spoilage within few hours of harvest. Additionally, enzymatic autolysis initiates immediately upon death in seafood resulting in soft flesh within short duration thereby limiting their shelf life and marketability (Arvanitoyannis & Stratakos, 2012). Presence of spoilage microorganisms and endogenous enzymes contribute to quality deterioration manifested as development of off-odours, discoloration and textural defects which are extremely undesirable. Hence, application of conventional preservation techniques is necessary to control these deteriorative reactions thereby maintaining quality and extending shelf life of the products (Kim et al., 2019).

Thermal and nonthermal methods are routinely employed in seafood industries primarily for safety and shelf-life enhancement purposes (Albulena et al., 2022). Heat treatments such as blanching, cooking and canning effectively eliminate pathogenic and spoilage bacteria consequently improving product safety and extending shelf life (Estevez & Oujifard, 2016). However, detrimental effects on nutritive components, formation of potentially toxic neo formed compounds and less consumer acceptance of sensory attributes are major issues associated with thermally processed seafood (Shikov et al., 2018). On the other hand, non-thermal approaches utilizing high hydrostatic pressure (HHP), pulsed electric fields (PEFs), ozonation, UV irradiation, etc. facilitate relatively better retention of original quality (Ramirez-Suarez & Morrissey, 2006). But incomplete inactivation of enzymes and existence of tailing cells after the treatment remain as limitations (Arvanitoyannis & Stratakos, 2012; Tappi et al., 2014). Hence combination treatments are gaining increasing attention wherein, a mild heat treatment is provided prior to or after the application of nonthermal method allowing synergistic effects on quality retention and safety enhancement (Albulena et al., 2022). However, the occurrence of some issues related to the application of these approaches has prompted the development of novel nonthermal food processing technologies for better quality foods with assured safety (Shikov et al., 2018; Kim et al., 2019). In this context, nonthermal atmospheric pressure plasma (NTAPP) is an emerging nonthermal technology gaining considerable interest among seafood researchers and the industry. Plasma denotes ionized gas composed of electrons, positive and negative ions, free radicals, electrons and quanta of electromagnetic radiation (UV photons) (Bazaka & Jacob, 2018; Kim et al., 2019). The reactive species generated in NTAPP especially the free radicals attack cellular constituents of microbes causing injury to microbial cell membrane and DNA damage leading to inactivation or death (Niemira & Sites, 2021). Besides microbial inactivation, plasma alters conformational characteristics of biomolecules including enzymes and structural proteins which affect their activity and functionality thereby influencing various physicochemical properties in foods (Tolouie et al., 2022). The ability of plasma to induce desirable changes in foods revealing its huge potential for maintaining quality has augmented research activities exploring its application in various foods including seafood (Tolouie et al., 2022). Hence, the current article reviews the recent literature on the effect of plasma on safety enhancement through microbial decontamination alongside discussing its efficacy to beneficially modify quality attributes for shelf-life improvement in seafood products. Research gaps are also identified and future perspectives on industrial level adoption of the technology are outlined.

Effects of Plasma on Seafood Quality Characteristics

Microbial Inactivation

The consumer rejection associated with rapid spoilage by opportunistic Gram-negative bacteria including Pseudomonas, Shewanella, Aeromonas, Vibrio, Flavobacterium, Psychrobacter, etc. is a primary concern in seafood industry (Kostaki et al., 2009). Additionally, several foodborne disease outbreaks have been linked to seafood contamination emphasizing the significance of decontamination for safety assurance (Novoslavskij et al., 2016; Al Bulena et al., 2022). Majority of the studies have explored aerobic plate counts and specific spoilage organisms as key target microbes to establish shelf-life improvement; while recent focus has shifted to evaluating plasma efficiency for eliminating pathogens as well including Listeria monocytogenes, Salmonella Typhimurium, Vibrio parahaemolyticus, Escherichia coli, Staphylococcus aureus, etc. Considerable reductions reaching 2-4 log units has been achieved in counts of both pathogenic and spoilage bacteria inoculated onto seafood products such as fish fillets, shrimps and oysters treated with plasma (Lee et al., 2016; Novoslavskij et al., 2016; Ziuzina et al., 2014). The ability of plasma activated water in reducing total viable counts and coliforms in bivalve shellfish samples has also been demonstrated revealing its application for shellfish depuration (Gupta & Nayyar, 2016).

Inhibition of Enzymatic Browning

Discoloration induced by oxidation and browning reactions is a primary quality defect affecting sensory attributes including appearance and texture which determines consumer preference for purchasing seafood (Kostaki et al., 2009). Polyphenol oxidases (tyrosinases) catalyze oxidation of endogenous phenolics especially tyrosine into quinones which polymerize nonenzymatically producing brown, black or red pigments (Kim et al., 2019). The ability of plasma for tyrosinase activity inhibition has been shown in shrimp, squid, and octopus samples (Cui et al., 2018; Liao et al., 2018). Improved colour and textural properties as a result have also been demonstrated in plasmatreated shrimps and oysters during refrigerated storage studies (Cullen et al., 2018; Mo et al., 2018).

Oxidative Stability

Lipid oxidation is a major reaction contributing to quality decay in high fat seafood particularly fatty fish varieties leading to rancid odours and flavours alongside textural defects limiting product acceptability (Kostaki et al., 2009). Contrary to common perception, promoting effects on lipid oxidation in plasma treated meat and some fish varieties has been demonstrated indicating possible prooxidant activity under certain conditions (Lee et al., 2016; Albertos et al., 2017). On the other hand, lipid oxidation inhibitory effects were also discernible as shown in the study by Mo et al. (2018) revealing the complex and variable nature of plasma chemistry. The key food matrix components (water, proteins, lipids, and antioxidants), treatment time, post treatment storage conditions and packaging type can potentially impact the oxidative effects induced by plasma. Modifying liquid systems using saline solutions as in oysters and shrimps may provide protective effects against prooxidant activity of plasma (Cullen et al., 2018). It can also facilitate better diffusion unlike solid fish counterparts. However, knowledge gaps exist regarding the specific mechanisms and chemical species governing the contradicting oxidative effects which warrants identification through advanced characterization tools.

Protein Functionality

Protein denaturation and degradation by endogenous proteolytic enzymes cause severe textural breakdown particularly in processed seafood compromising product quality (Kostaki et al., 2009). Reduction in total volatile bases content and lower biogenic amine levels are indicative of protein breakdown inhibition in plasma treated seafood such as pacific white shrimps, oysters, carp surimi gels, etc. (Cullen et al., 2018; Liao et al., 2020; Mo et al., 2018). Hardness retention and folding characteristics of myosin heavy chain pointed alterations in protein confirmation and aggregation properties as possible mechanism for textural preservation by plasma (Liao et al., 2018).

Research Gaps and Future Directions

The reviewed literature provides substantial evidence on the efficacy of plasma technology for microbial safety and quality enhancement in diverse seafood products. However, variations are discernible in antimicrobial and physicochemical effects based on key intrinsic and extrinsic determinants necessitating optimization studies. Identification of specific plasma reactive species and characterization of their interactions with target microbes and food components requires in-depth investigation for better process control. Studies demonstrating actual shelf-life extension under realistic environments are limited which needs to be addressed through systematic storage trials. Consumer studies evaluating sensory attributes and overall acceptance of plasma processed seafood are vital for ensuring marketability which remains scarcely explored. Besides safety and quality, emphasizing sustainability by waste reduction and extraction of high value compounds can further enhance the scope for plasma technology. Scale up efforts through designing large plasma units and integration into existing processing lines is important for feasibility assessment from industrial perspective. Overall, plasma technology holds great promises for enabling cleaner and safer sea.

CONCLUSION

The emerging nonthermal food processing technology - atmospheric pressure plasma has exhibited tremendous potential for enhancing microbial safety while beneficially modifying enzymatic and physicochemical properties in diverse seafood products. The ability to generate a cocktail of reactive species at ambient temperatures provides advantages over conventional thermal and nonthermal techniques with regard to quality retention. Considerable research has focused on investigating antimicrobial effects and analyzing biochemical changes induced by plasma in various seafoods. However, storage trials demonstrating actual shelf-life extension are limited. Besides microbiological quality, emphasis on sustainability aspects by waste reduction and recovery of valuable compounds can further widen the application scope. Although few hurdles exist regarding process control and optimization, noticeable advancements made in customizing equipment design shows that these can be effectively addressed in coming years. With dedicated efforts on scaling up technologies alongside sensory and consumer studies to ensure market viability, transition from lab to industry could be accelerated. Overall, the emerging evidence strongly suggests that plasma technology can pave way for better quality and safer seafood products in near future through its integration into existing processing operations.

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