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Application of sous vide cooking to aquatic food products: a review

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Abstract

With the development of cooking technology towards a more quantitative science, consumers have begun to consider cooking as no longer limited to traditional methods. Through continuous recognition, the concept of molecular cooking has gradually entered the mainstream. In addition to the traditional way of conceiving cooking, and on the premise of ensuring food safety and adequate nutrition, food components considered at the molecular level and the use of modern cooking equipment in the preparation of innovative dishes can be combined by employing physical, chemical, and biological strategies. The sous vide (SV) cooking method refers to cooking using precisely controlled temperature and time of vacuum-packed food, which results in a food that is safe, nutritious, convenient, and easy to prepare. As a result, healthy SV preparations are widely accepted among families as well as single and elderly people. This technology has been widely used in catering, food retail, and health food market. In this review, important aspects of the origin and development of SV technology as well as its impact on the quality of aquatic products are discussed. In addition, current existing problems, and prospects to better promote SV technology in aquatic product processing are highlighted. Collectively, this review provides references for the application of SV cooking technology to the industrial processing of aquatic products.

Keywords: sous vide cooking; aquatic product; quality; application; technology.

Practical Application: The sous vide cooking described in this paper has good advantages and can provide a theoretical reference for the deep processing and industrial production of aquatic products.

1 Introduction

Aquatic products have unique flavor, low fat content, high nutritional value and protein content. In particular, fish flesh is delicate, composed of protein that is easily absorbed, being one of the main sources of human food. In recent years, consumers have become more focused on ready-to-eat aquatic products as a means to obtain nutritional, convenient, and safe foods. However, aquatic products are highly susceptible to microbial contamination and spoilage. In fact, squid is currently sold fresh and frozen. The intensive processing of aquatic products and their extended storage period have largely become significant issues in the aquatic food product chain.

The excessive pursuit of shape and color in foods can be associated with the use of traditional cooking methods that employ high temperature for cooking and stewing as well as deep-fried baking. In the process of overheating, quality of aquatic products decline, and nutrient loss may lead to the production of toxic and harmful substances, such as heterocyclic amines and benzopyrenes (Cui et al., 2021). The emergence of sous vide (SV) cooking technology solves these problems to a certain extent and can better preserve quality and nutritional value of aquatic foods whilst reducing the production of harmful substances to ensure food safety. Therefore, convenient and healthy SV-prepared products are immediately accepted among families, single and elderly people. Foods cooked under vacuum and at low temperatures appeal to the food industry due to their convenience, nutrition security, low cooking loss, and high yield. The catering and the food retail industries, as well as restaurants, transportation systems (aviation, railway, and shipping), military, hospitals, health food markets, and schools can also be considered potential markets for the SV technology (Cui et al., 2021).

SV technology refers to the method of cooking vacuum-packed food under precise temperature and time control (Baldwin, 2012). Compared with traditional cooking methods, the precise control of temperature and time guarantees good maturation and taste of the food, and vacuum packaging helps to preserve food nutritional quality and shelf life. Hospitals first used the SV technology to disinfect packaged foods in order to improve food safety and storage. In 1974, the SV technology was applied for the first time in the production of gourmet food. For instance, chefs George Pralus and Pierre Troisgros found that foie gras sealed in a plastic bag and cooked at a precise temperature had minimal fat and moisture loss, which thus contributed to maintain its taste (Fetterman et al., 2016). Simultaneously, the French scientist Bruno Goussault cooperated with fast food companies and hospitals to formally introduce the SV technology; in 1986, he teamed up with the famous French chef Joël Robuchon to create the first national catering project for the French National

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Railways using the SV technology to other sizeable commercial foodservice organizations (Fetterman et al., 2016). Subsequently, SV was introduced in the United States, the United Kingdom, and Canada, and has been used since then by some of the world's top restaurants. At the beginning of the 21st century, Michelin-starred restaurants started to employ the SV technology in their preparations. Despite these breakthroughs, SV technology is still mainly applied in professional gastronomy. More recently, the SV technology has been attracting more attention, and countries have begun to introduce cheaper and more portable immersive circulators, and the number of users of the SV technology in professional kitchens and homes has increased dramatically. Research on SV technology has also been conducted onto different aquatic products (Table 1).

The impact of heat treatment on aquatic products' physicochemical and organoleptic characteristics is still poorly documented. Therefore, this study explores the effect of different heat treatment methods on aquatic's physical and chemical properties and provides ideas for deep processing of aquatic food products.

2 Effect of sous vide cooking on the quality of aquatic food products

2.1 Sensory evaluation

Impact on texture of aquatic food products

Heating used as part of the SV method significantly affects shear force, springiness, cohesiveness, and chewiness of aquatic food products, whereas changes in treatment duration did not lead to statistically significant differences in texture (Christensen et al., 2011; Garciasegovia et al., 2007; Roldan et al., 2013). Cui et al. (2019) found that squid cooking loss and hardness increased with increasing SV temperature (55-85 °C). Gök et al. (2019) showed a higher moisture content and lower cooking losses in SV *gluteus medius* (80 °C, 75 min) compared to the convection oven (core temperature 80 °C, 55 min). Qiu & Wu (2021) also found that cooking loss of large yellow croaker (*Larimichthys crocea*) increased at higher heating temperatures (60 and 70 °C), but prolonged time (heating from 5 to 10 min) had little effect on cooking loss. Cropotova et al. (2019) showed that the hardness of mackerel fillets increased with increase in SV temperature (60-90 °C), and that hardness of mackerel fillets cooked under vacuum for 10 min at 90°C was maximum. In addition, lysis of fish meat connective tissue in the temperature range of 50-70 °C leads to soft meat, while denaturation of myogenic fibrous proteins occurring at higher temperatures results in hard meat (Baldwin, 2012). Cooking loss is also attributed to hardening of aquatic products after heating. Importantly, application of SV to proteins of animal origin should be submitted to sufficient cooking time to allow complete dissolution of collagen thereby reducing hardness of the final product. When temperature in the core of the meat product is approximately 60 °C and heating time is extended, a more tender meat product is obtained. Laakkonen et al. (1970) and Machlik & Draudt (1963) found that a prolonged cooking time at approximately 60°C avoided increase in meat hardness often observed at higher temperatures and improved meat tenderness after maintaining the temperature for 4 h. These observations were further confirmed in scallops; when SV was applied at 65 °C for 20 min, scallops developed good taste and full shape, and contents of taurine, protein, and vitamins were significantly higher than those in scallops

Table 1. Comprehensive review of previously published studies on the application of sous vide (SV) technology to aquatic products.

Reference	Aquatic product	Cooking conditions		Highlights
		Temperature (°C)	Duration (min)	
Qiu & Wu (2021)	Large yellow croaker (*Larimichthys crocea*)	60 or 70 (core temperature)	5 and 10	Rosemary extract inhibited lipid oxidation of large yellow croakers during storage; SV-treated fish (70 °C, 5-10 min) was stored at low temperature for at least two weeks
Redfern et al. (2021)	Salmon	52, 65, and 80	15	Mild SV cooking preserved antithrombotic potency of salmon polar lipids (PL) and the ratio of n-6/n-3 polyunsaturated fatty acids was kept low
Cui et al. (2020)	Squid (*illex argentinus*)	60	30	SV-treated squid had fewer volatile components since vacuum packaging reduced fat oxidation and aldehydes production
Pino-Hernández et al. (2020)	Pirarucu (*Arapaima gigas*)	60	9.48	SV treatment on pirarucu preserved its good quality up to day 49 of storage
Llave et al. (2018)	Tuna	50 and 59	13-62	Water retention capacity of salmon muscles decreased as temperature increased during heating; heating at a lower temperature (50 °C) and prolonged cooking time (62 min) did not significantly impacted cooking loss
Espinosa et al. (2015)	Seabream (*Sparus aurata*)	60 (core temperature)	46	Microbiological quality of seabream remained stable after treatment with SV and high pressure
Cadun et al. (2016)	Pink shrimp (*Parapenaeus longirostris*)	75 and 95	10-15	SV treatment (95 °C for 15 min) extended shrimp shelf life as demonstrated by sensory evaluation and microbiological analysis

prepared using the traditional cooking method (Yao, 2013). In addition, sea cucumber prepared with SV at 70 °C for 60 min had moderate hardness, crispness, smooth taste, and flexibility (Li, 2013). Moreover, Espinosa et al. (2016) found that flavor and texture of *Sparus aurata* were best when cooked at 60 °C for 12-15 min. In addition, it has been suggested that the SV technology can replace pre-treatment of tender meat technology (Suriaatmaja & Lanier, 2014).

Impact on color of aquatic food products

Color is one of the most direct and essential sensory indicators of food quality. Aquatic food products are prone to discoloration due to heme oxidation during heat treatment. In addition, cooking of aquatic products at high temperatures for a prolonged time will also produce meat with unattractive colors (Bramblett et al., 1959). Conversely, aquatic food products cooked by SV conserve attractiveness and consistency. Vacuum packaging enables myoglobin in muscles to remain in the state of deoxymyoglobin which is relatively resistant to heat-induced degeneration (Naveena et al., 2017); therefore, oxygen-free SV leads to a significant improvement in product color and is superior to traditional boiling products. Salmon cooked with SV at 65 °C and 90 °C for 15 min develops noticeable difference in terms of color, in which salmon cooked at 90°C developed a less appealing color, while color of salmon cooked at 65 °C remains unchanged (Fagan & Gormley, 2004; González-Fandos et al., 2005). Tang et al. (2017) found that color of catfish cooked at 60, 70, and 80 °C was significantly brighter than that of raw fish and remained unchanged at 4 °C for 24 days. Dong et al. (2018) found that when scallop adductor muscle was cooked at 55 °C for 32 h using SV technology, brightness was not affected by increase in redness, whereas yellowness decreased with prolonged cooking time. Collectively, the use of SV technology differently affects color development in cooked aquatic food products. Furthermore, for the same aquatic product, the use of different cooking temperatures and time, as well as colored sauces will have a significant impact on color development of aquatic food products.

Impact on flavor of aquatic food products

Consumers' preference for food flavor is derived from a multidimensional and complex combination of stimuli which include taste, aroma, and mouthfeel. The application of SV helps to maintain excellent food taste and color and to control soluble flavor compounds and volatile aroma substances by precisely controlling temperature and cooking time. Mohan et al. (2017) found that SV-cooked shrimp conserved its unique smell of fresh seaweed on the sixth day of storage, whereas shrimp processed using conventional cooking method had lost the smell of freshness after vacuum packaging. It is generally believed that heating at temperatures above 70°C help to shape the profile of volatile aromatic compounds in mature meat, whereas SV at temperatures below 50-60 °C does not lead to a pleasant, cooked meat flavor (Calkins & Hodgen, 2007; Cross et al., 1976). Flavor and taste of low-temperature cooked meat derive from a combinatory effect of products originated from fatty acid degradation and non-volatile compounds (Aaslyng & Meinert, 2017). In studying the impact of different cooking methods on squid flavor, Cui et al. (2020) used headspace-gas chromatography–ion mobility spectrometry to reveal that aroma and taste of SV-processed squid (60 °C, 30 min) were significantly lower than those of traditionally cooked squid (steamed and boiled). The main reason for the lack of flavor in SV-processed squid is that vacuum packaging reduces the degree of fat oxidation and leads to reduced production of aldehydes compared to traditional cooking methods. Similarly, several studies have reported that as heating treatment intensifies (higher temperatures and/or prolonged cooking time), volatiles derived from lipid oxidation decrease, and the content of volatile compounds derived from the degradation of amino acids and/or thiamine increases (del Pulgar et al., 2013; Roldan et al., 2015). Bozova & İzci (2021) found that the addition of rosemary and oregano extracts to SV-cooked meagre (*Argyrosomus regius*) fillets during refrigeration improved flavor (taste and smell) of fish and had a good antibacterial effect which contributed to control the total number of mesophilic and *psychrophilic* aerobic bacteria on day 42 of storage (4 ± 1 °C); moreover, contents of total volatile basic nitrogen, thiobarbituric acid, and trimethylamine-nitrogen did not exceed the recommended limits throughout the storage period.

2.2 Impact on protein and fat contents in aquatic food products

Aquatic food products have long been regarded as the primary source of high-quality and easily digested protein, and fish-based products are rich in long-chain omega-3 fatty acids eicosapentaenoic acid and docosahexaenoic acid. However, polyunsaturated fatty acids in aquatic products are easily oxidized during traditional cooking methods in which high temperatures are employed, such as in frying and roasting, which reduces the nutritional value of aquatic food products. SV is gentler than traditional cooking methods and enables effective retention of nutrients in aquatic products (Estévez et al., 2011; Tacon & Metian, 2013). Pino-Hernández et al. (2020) revealed that cooking of pirarucu (*Arapaima gigas*) by SV (60 °C, 9.48 min) led to a very good retention of all nutrients (≥60%), especially of proteins. In addition, when tilapia meat was heated by SV at 45 °C, degree of protein oxidation increased (Ko et al., 2007). Dong et al. (2018) found that carbonyl content in scallop adductor muscle increased by nearly seven times after SV (55 °C) treatment for 27 h due to the large amounts of arginine, proline, lysine found in the meat. Conversion of amino acid residues to carbonyl derivatives, such as α-aminoadipate and γ-glutamic acid semialdehyde (Roldan et al., 2014), and a nearly 30% thiol loss were observed in SV-cooked scallop adductor muscle, and a similar phenomenon occurs when threadfin bream (Yongsawatdigul & Park, 2003) and tilapia meat are heated at 95 °C. During heating, sulfhydryl groups in actin have strong reducing ability and their number decreases after intermolecular and intramolecular oxidation.

Lipids in aquatic products are also easily oxidized, especially after processing using high-temperature-based conventional cooking methods (e.g., frying and deep-frying). SV employs vacuum packaging as a means to reduce the degree of oxidation during the reheating process of aquatic products. Mohan et al. (2017) found that, compared with ordinary air packaging, vacuum packaging of SV-cooked shrimp (core temperature 80 °C, 10 min) suppressed oxidation of volatile bases, indole, and lipids during storage ($p < 0.05$). Using low temperature pasteurization (65 °C), retention of unoxidized unsaturated fatty acids in SV aquatic food products is generally higher compared to conventional cooking methods at temperatures above 85 °C (Schellekens, 1996). In addition, both triglycerides and phospholipids in fish meat contain long-chain polyunsaturated acyl groups, which are particularly susceptible to oxidation due to their higher degree of unsaturation. Marine fish are known to be rich in unsaturated fatty acids such as eicosapentaenoic acid and docosahexaenoic acid (Goel et al., 2018). In particular, salmon is rich in biologically active compounds, especially in lipids with cardioprotective effect. Dietary guidelines recommend consumption of oily fish (such as salmon) once a week, and regular consumption has been shown to be associated with cardioprotective effects (Gil & Gil, 2015; Goel et al., 2018). Redfern et al. (2021) suggested that use of SV (52-65 °C, 15 min) effectively preserved bioactive components (polar lipids) in both brined and un-brined salmon, which showed anti-thrombogenic properties against platelet aggregation induced by the potent inflammatory mediator platelet-activating factor (Tsoupras et al., 2018, 2019). Contrastingly, high-temperature SV (80 °C, 15 min) led to reduced antithrombotic properties of polar lipids in salmon and reduced content of polyunsaturated fatty acid eicosapentaenoic acid in the absence of brine. Thus, the SV technology can limit oxidation of proteins and lipids in aquatic food products and, to a certain extent, nutrient loss.

2.3 Impact on safety of aquatic food products

Rate of spoilage of fish meat after slaughter is closely related to the initial microbial load found in meat. Total volatile base nitrogen (TVB-N) comprises ammonia and lower amines produced during decay of aquatic products as a result of bacterial growth and enzymatic activity, which is an important indicator to measure the degree of decay of aquatic food products. By combining low-temperature heat treatment with vacuum packaging, endogenous proteases and lipases in aquatic food products are inactivated, thereby delaying spoilage of aquatic products while maintaining sensory and nutritional quality (Baldwin, 2012). Tang et al. (2017) found that, compared with raw catfish slices, cooking of catfish at 70 °C for 5 min followed by refrigeration can significantly delay increase in TVB-N content and inhibit growth of microorganisms during storage, thereby prolonging shelf life of catfish meat by twelve days. Since SV employs vacuum and sealing in a plastic bag, an anaerobic environment is formed during heating treatment and subsequent storage, which can effectively prevent bacteria growth (Frau et al., 2021; Yehia et al., 2020). Moreover, compared to conventional heating, the synergistic effect of vacuum packaging and heating employed during SV was shown to lead to a three-log reduction in bacterial load in shrimp (Mohan et al., 2017). In addition, Diaz et al. (2009) found that SV applied to salmon (80 °C, 45 min) effectively prevented growth of aerobic and anaerobic *psychrophilic* bacteria, lactic acid bacteria, molds and yeasts, and *Enterobacteriaceae* during cold storage. Espinosa et al. (2016) discussed the impact of SV on the microbial load of seabream and found that *Salmonella* and *Listeria monocytogenes* were not detected in the samples.

Different SV temperatures and cooking times applied to the same aquatic product can impact microbiological safety and shelf life differently. González-Fandos et al. (2005) evaluated cooking of salmon using different combinations of temperature and time (65 °C for 5 min followed by storage at 2 °C; 90 °C for 10 min followed by storage at 10 °C; and 90 °C for 15 min followed by storage at 2 °C) and found that shelf life of salmon was 21 days for the first two treatments and 45 days for the latter, which was therefore considered the most effective treatment to ensure salmon safety and extend its shelf life. In addition, the microbial load of pirarucu (*Arapaima gigas*) treated by SV (core temperature 60 °C for 9.48 min) did not exceed limit values during storage for 49 days, although an increase in the microbial load was observed (total mesophilic count: 3.50 log CFU/g; total psychrotrophic bacterial count: 2.90 log CFU/g) (Pino-Hernández et al., 2020). In addition, previous studies indicated that combining the SV technology with other technologies leads to effective control of pathogenic microorganisms in aquatic food products and further extends shelf life (Bolat et al., 2019). Bongiorno et al. (2018) revealed that combining SV (85 °C for 10 min in core) with chilling led to increased quality of mussels and prolonged shelf life to 21 days. In addition, using SV treatment in mackerel fillets combined with irradiation (2.5 kGy and 5 kGy) was shown to delay microbial growth and led to extended fish shelf life (Dogruyol & Mol, 2017).

3 Challenges and prospects

As a mild cooking method, SV can maximize retention of nutritional quality of aquatic food products and extend their shelf life compared to traditional cooking methods. In addition, since SV enables precise control of cooking temperature and time, it can guarantee consistency and reproducibility of cooking results, which is unmatched by traditional cooking methods. At the same time, the SV technology is simple to operate and does not require professionally trained personnel, which reduces labor cost and collectively proves convenient for industrial application of SV to aquatic seafood products. Current research has mainly explored SV to study nutritional quality, microbial safety, and shelf life of aquatic food products in vacuum and low-temperature cooking. Although promising results have been achieved, further research is still needed to improve the SV technology, with the aim to remove fishy smell of SV-cooked aquatic products, and few varieties of SV-cooked aquatic products have been investigated. As a convenient, nutritious, and health product, SV-cooked aquatic products are expected to receive increasing attention and gain broader market prospects in future years.

Ethical statement

This article does not contain any research that would require ethical statements.

Conflict of interest

The authors have no conflicts of interest.

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