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REVIEW ARTICLE DERLEME MAKALESİ

ALTERNATIVE SEAFOOD PRESERVATION TECHNOLOGIES: IONIZING RADIATION AND HIGH PRESSURE PROCESSING

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Abstract: Seafood includes a number of high value food products with considerable economic importance. Fish freshness is the most important and fundamental single criterion for judging the quality of fish and fishery products. Fish is known to be a perishable product that requires effective preserving method to maintain quality and avoid food poisoning. Irradiation and high pressure treatment has been used to extend the shelf life of sea foods, especially fish and fish products, due to its microbial inhibition. Irradiation has been proposed as an alternative technique to thermal processing to destroy foodborne pathogens and spoilage organisms in order to enhance safety and shelf life of perishable foods. High hydrostatic pressure processing (HHP) is an alternative for pasteurization of food products as a non-thermal preservation method. HHP treatment can result in microbial destruction and product stabilization without affecting sensory qualities of foods. In this paper, the use of irradiation and high pressure treatments in seafood products preservation were reviewed.

Keywords: Fish, Seafood, Irradiation, High pressure, Auality; Food safety

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Öz:

Su Ürünlerinde Alternatif Koruma Teknikleri: İyonize Radyasyon ve Yüksek Basınç Uygulamaları

Su ürünleri ekonomik önemi yanında yüksek değerli gıda ürünleri içinde yer alır. Balık ve balık ürünlerinin kalitesinin belirlenmesinde en önemli kriter tazeliktir. Balık ürünleri, gıda zehirlenmelerinin önlenmesi yanında kalitesinin korunması bakımından etkili bir koruma uygulama gerektiren hassas bir ürün grubudur. Işınlama ve yüksek basınç uygulamaları balık ve balık ürünlerinde mikrobiyal inhibisyonda, su ürünlerinin raf ömrünün artırılmasında etkilidir. Işınlama gıda kaynaklı patojenlerin ve bozulmadan sorumlu mikroorganizmaların yıkımı ile gıdaların raf ömrünü ve gıda güvenliğini artırmak için alternatif bir yöntem olarak önerilmektedir. Yüksek basınç uygulaması ısıl işlem olmayıp pastörizasyona alternatif bir muhafaza metodudur. Yüksek basınç uygulamaları ürünün duyusal özelliklerini etkilemeden mikrobiyolojik tehlikeleri elimine eder ve stabilizasyonu sağlar. Bu derlemede, su ürünleri muhafazasındaki ışınlama ve yüksek basınç uygulamaları hakkında bilgi verilmiştir.

Anahtar Kelimeler: Balık, Su ürünleri, Işınlama, Yüksek basınç, Kalite, Gıda güvenliği

Introduction

The role of fish in nutrition is being increasingly recognized as it supplies a good balance of protein, vitamins, and minerals (calcium, phosphorus, and iron) associated with relatively low-calorie content. Apart from having a better protein and calorie ratio than red meat, sea foods are also rich in unsaturated fatty acids (Sioen, 2007).

Seafood consumption varies greatly across individuals, families, cultures and countries. As with any complex human behaviour, variation in seafood consumption will be influenced by many inter relating factors, such as properties of the food (quality and sensory attributes), characteristics of the individual (preferences, personality and knowledge), or characteristics of the environment such as availability, situation and seasons. Generally, consumers prefer fresh fish to frozen, canned, salted, pickled, smoked or dehydrated products (Erkan and Çağıltay, 2011).

The high levels of moisture, nutrient content, weak connective tissue and neutral pH of fresh fish render itself as a perishable product. The quality of fish is composed of three separate components. These include (1) initial quality of the fish (intrinsic quality), that is, the quality at the time of the catch, depending on catch location, species, size, sex, composition, etc.; (2) quality, influenced by the handling conditions starting from harvest, on-board handling, icing, filleting, gutting etc.; and (3) the microbial quality (initial microbiota, existance of pathogens). The spoilage of fish is usually caused by biological reactions such as oxidation of lipids, activities of the fish's autolytic enzymes, as well as the loss of protein functionality, microbial growth and metabolic activities, resulting in a short shelf life of fish and other seafood products (Ababouch et al., 1996; Ashie et al., 1996; Erkan, 2003). Thus, maintenance methods to keep the quality of seafood's and delay the deterioration of fresh fish during storage have always had significant place to pursue for fisheries scientist.

Mostly used traditional preservation techniques such as chilling and super chilling generally insufficient for the quality maintenance, long shelf life and safety of the product. In terms of inhibition or elimination of quality loss and pathogen microorganisms in seafood, newly developed technologies are coming into prominance. The most known of these technologies are radiation, high pressure processing (HPP). The effectiveness of these technologies have been proved by researchers (Jeevanandam et al., 2001; Savvaidis et al., 2002; Linton et al., 2003; Zare, 2004; Chéret et al., 2005; Ramirez-Suarez and Morrissey, 2006; Gómez-Estaca et al., 2007a; Özden et al., 2007a,b; Yağız et al., 2007; Arvanitoyannis et al., 2009; Erkan et al., 2010; Erkan and Üretener, 2010; Günlü et al., 2014)

Since the global demand for fishery products is increasing (Erkan and Çağıltay, 2011), there is a need for efficient preservative methods. The major problem with respect to distribution of seafood or fishery products is their susceptibility to spoilage, mainly due to the contamination of spoilage and pathogenic microorganisms (Erkan, 2003). Novel technologies (food irradiation and high pressure treatment) are process that have proven to be successful (Ashie et al., 1996), not only in ensuring the safety, but also in extending the shelf life of fresh meat, chicken, fish and fish products because of its high effectiveness in inactivating pathogens and spoilage organisms without deteriorating product quality.

Irradiation

Food irradiation is a process for the treatment of food products to enhance their shelf life and to improve microbial safety. Generally, ionizing radiations emitted by radioisotopes, Cobalt-60, and Cesium-137 are used for food preservation. According to many researchers food irradiation, sometimes called “cold pasteurization,” has been described as the most extensively studied food processing method in the history of humankind and is endorsed by virtually all medical and scientific organizations. Food irradiation is a process in which irradiation energy, which travels through space or matter in invisible waves, is applied to kill microorganisms or insects in foods. The quantity of energy absorbed by the food during irradiation is called “absorbed dose.” The international unit for absorbed dose is the Gray (Gy). The dose used varies according to the type of food and the desired effect. Treatment levels can be grouped into three general categories: (1) “Low” dose, up to 1 kGy, (2) “Medium” dose, 1–10 kGy and (3) “High” dose, greater than 10 kGy. Medium dose is used to reduce spoilage and pathogenic microorganisms on various foods, to improve technological properties of food and to extend the shelf-life of sensitive foods (Mendes et al., 2005; Venugopal et al., 1999).

Positive information reported regarding the impact of irradiation dose on the shelf life and micro flora and sensory and physical properties of fish, shellfish, molluscs, and crustaceans. The first studies on this subject have been on the determination of the optimum dose (Arvanitoyannis et al., 2009; Snauwert et al., 1977; Reinacher and Ehlermann, 1978) (see Table 1). The optimum irradiation dose for Herring (*Clupea herring*) was found to be 1-2 kGy, which yields a shelf life of 10-14 days at 2°C (Snauwert et al., 1977). According to Reinacher and Ehlermann, (1978) have been reported the optimum dose 1-2 kGy for Ocean perch (*Sebastodes alutus*) and this application which led to a shelf life 25-28 days at 0.6 °C.

Optimum irradiation dose for the different fishes have been reported and have been found suitable 1.5–3 kGy, for mackerel (*Rastrellinger kanagurta*) 1.5 kGy, for White pomfret (*Stomateus cinereus*), Black pomfret (*Parastomatus niger*) 1 kGy, for Sole (*Parophyrs vetulus*) 2–3 kGy (Arvanitoyannis et al., 2009). The shelf life of Bombay duck (*Harpodon nehereus*), under refrigeration was shown to be about 5–7 days. Radiation doses of 1.5-2.5 kGy extended the shelf life to about 15–20 days (Kumta et al., 1970). According to Chuaqui-Offermanns et al. (1988), whitefish (*Coregonus clupeaformis*) were gamma irradiated at 0.82 and 1.22 kGy, and stored at 3°C for 17-21 days. The non-irradiated samples exhibited a sensory shelf life of 7-8 days, whereas those of the irradiated ones were extended by 10-13 days. Ahmed et al. (1997) studied irradiated Nagli fish (*Sillago sihama*) at a dose of 2-3 kGy gave a shelf life of 19 days stored at 1-2°C in comparison to a storage life of 8 days for the non-irradiated samples. According to Mendes et al. (2005), fresh Atlantic horse mackerel (*Trachurus trachurus*) were gamma irradiated at 1 and 3 kGy, and stored in ice at 0 ± 1°C for 23 days. The non-irradiated samples exhibited a sensory shelf life of 8 days, whereas those of the irradiated ones were extended by 4 days. Özden et al. (2007a;b) determined the influence of gamma irradiation (2.5-5 kGy) and post-irradiation storage up to 15-17 days at 4°C on some chemical and microbiological criteria of sea bass and sea bream. The total volatile basic nitrogen formation, thiobarbituric acid values and total viable count was lower in irradiated fish than in the non-irradiated. The synergistic effect of irradiation in conjunction with other techniques such as salting, smoking, freezing, and vacuum packaging has also reported (Savvaidis et al., 2002; Özden et al., 2007 a, b; O’bryan et al., 2008; Arvanitoyannis et al., 2009). Jeevanandam et al. (2001) reported shelf life of non-irradiated and irradiated (1 and 2 kGy) Threadfin bream (*Nemipterus japonicus*) packaged in polyethylene pouches and dipped in 10% (w/w) sodium chloride was 9 day and 14-28 day. Total mesophilic counts for salted vacuum-packed, refrigerated control and irradiated sea bream reached an average value of 7 log cfu/g after 14 days (0 kGy), 23 days (1 kGy) and 40 days (3 kGy) (Jeevanandam et al., 2001). Savvaidis et al. (2002) reported counts of 7 log cfu/g for vacuum packed trout after 9, 14 and 24 days for non-irradiated and irradiated samples at 0, 0.5 and 2 kGy, respectively. Kasımoglu et al. (2003) studied irradiated sardines (*Sardina pichardus*) at a dose of 2-3 kGy and vacuum packaged in polyethylene bags gave a shelf life of 21 days stored at 4°C in comparison to a storage life of 10 days for the non-irradiated samples. Chouliara et al., (2005) reported that initial total volatile basic nitrogen (TVB-N) levels of vacuum packed-irradiated (1–3 kGy) sample stored under refrigeration sea bream were 27.5 mg/100 g, 27.3 mg/100 g and 25.1 mg/100 g, reaching the acceptable limit at day 10 in control, at day 21 and 28 for 1 and 3 kGy irradiated sea bream.

The positive effects of irradiation in quality of sea are as follows:

- Microbial load decreased,
- Lower total volatile basic nitrogen value,

The negative effects of irradiation in quality of sea are as follows:

- Based on species, irradiation may cause increase in Tiobarbituric acid (TBA) values as a result of radiolytic products formation. However, in most of the studies it has been claimed that mentioned values have lower compared to non - treated samples.
- Some fatty acids decreased by irradiation treatments at all doses.
- Thiamin loss was more severe at higher doses (≥4.5 kGy), whereas riboflavin was not affected.
- L* value decreased, whereas a* and b* values increased throughout storage.
- pH values decreased gradually (Chouliara et al., 2005; Genç and Diler, 2013; Jeevanandam et al., 2001).

High Pressure Treatment

High-pressure treatment is effective in reducing microorganisms, and is known as a good method for inactivating pathogens in food materials. Pressure treatment causes changes in morphology, cell wall and membrane, biochemical reactions, and genetic mechanisms of microorganisms. High-pressure processing offers a number of advantages over conventional thermal processing. For instance, high pressure inactivates spoilage and pathogenic bacteria, without effecting the vitamin content, colour and flavour. This allows the production of wholesome foods, with little loss in nutritional and sensory qualities (Amanatidou et al., 2000; Yuste et al., 2001; Balasubramaniam and Farkas, 2008). High hydrostatic pressure (HHP) treatment, in combination with good refrigeration and handling practices, provides a means to increase fish product shelf-life (Linton et al., 2003; Zare, 2004; Chéret et al., 2005; Ramirez-Suarez and Morrissey, 2006; Yağız et al., 2007; Erkan et al., 2010; Erkan and Üretener, 2010; Günlü et al., 2014). Although there is a increasing interest in the application of HHP technology to fish-based products, limited research has been performed regarding the use of HHP in the development of high-quality fresh seafood products (Linton et al., 2003). Zare (2004) determined the effects of HHP (at 200 MPa for 30 min and 220 MPa 30 min) on microbiological, chemical, and sensory properties of tuna stored in a refrigerator (4ºC). Results of this study indicate that the shelf life of HHP treated and untreated tuna stored in refrigerator as determined by the overall acceptability sensory scores was 18 and 6 days, respectively. Ramirez-Suarez and Morrissey (2006) found that high pressure (275 MPa and 310 MPa for 2, 4 and 6 min) increased the shelf-life of albacore tuna to >22 days at 4ºC based on microbiological numbers. Erkan et al., (2010) found that a pressure treatment of 220 MPa for 5 min at 3ºC increased the microbiological shelf-life of red mullet, based on a psychrotrophic count of 10^6, from 11 days at 4ºC to 15 days. Treatment at 330 MPa for 5 min at 25ºC increased it further to 17 days. Erkan and Üretener (2010) also reported that a pressure treatment of 250 MPa for 5 min at 3ºC and 15ºC increased the microbiological shelf-life of gilt-head bream from 10 days to 16 and 13 days respectively. It is apparent that for all microorganisms examined, obtained populations were higher for unpressurized fish than those for pressurized fish species stored in a refrigerator throughout the entire storage period. Günlü et al., (2014) determined the effect of HHP on the shelf life of vacuum packed rainbow trout fillets. In accordance with chemical and microbiological results 4 days shelf life extension was determined for the chilled stored (4±1 °C) fillets after HPP application. Lower microbiological counts have been reported for pressurized tuna (Zare, 2004), sea bass (Chéret et al., 2005), albacore tuna (Ramirez-Suarez and Morrissey, 2006), mahi mahi-rainbow trout (Yağız et al., 2007) and rainbow trout (Günlü et al., 2014). Practices in this regard are presented in Table 3. Pressures between 200 and 600 MPa are commonly applied to extend the shelf-life of products decreasing the counts of spoilage microbiota. After HP treatments at 200 MPa for 30 and 60 min, fresh salmon resulted in a product with total viable counts lower than 100 cfu/g (Amanatidou et al., 2000). HP processing of cold-smoked dolphin fish at 300 MPa for 15 min reduced the counts of aerobic and lactic acid bacteria to levels below the detection threshold for three weeks (Gómez-Estaca et al., 2007b). HP technologies can have detrimental effects on the quality of smoked fish. Colour changes following treatments include higher L* values associated with higher opacity. Harder textures and lipid oxidation are also alterations reported in pressurized smoked fish products. Of particular relevance is smoked salmon, one of the most sensitive fish products to this processing technology, which intense red colour lightened after pressurization. The effect of HP on sensory quality varies within various seafood products and different pressurization conditions. Proteins can be denatured by the process, especially above 300 MPa. This may result in raw high protein products such as beef and fish taking on a "cooked" appearance, depending on processing conditions used (Lakshmanan et al., 2005; Karim et al., 2011). Matser et al. (2000) observed that pressure at 100 MPa did not affect the hardness of frozen cod while treatments at 200 and 400 MPa increased this characteristic. Increased rates of lipid oxidation during the storage of pressurized fish (Cheah and Ledward, 1996) were related with high concentration of polyunsaturated fats and oxidative changes induced by pressure (Angsupanich and Ledward, 1998). According to the results of this study, advantages of HHP in seafood were reported as lower microbial count and higher shelf life. Disadvantage of HHP in sea food are colour changes, lipid oxidation, and texture changes (Medina-Meza et al., 2014).

Conclusion

High pressure processing and irradiation technology significantly decrease the rate of microbial and chemical spoilage developed in packed and unpackaged raw fish stored on ice and refrigerator. As a result of this reduction, the shelf-life of perishable products (i.e. sea foods) are prolonged from 50 % to 75 % compared to control groups. By taking into account the category of seafood which is perishable, shelf-life extension is much higher when novel technologies are used compared to applied traditional methods. Additionally, higher rate of food borne pathogen elimination could be achieved with these mentioned technologies.

Table 1. The optimum radiations dose for different sea foods and the shelf life of fish

Seafood	Optimum dose	Maximum shelf life	References
Ocean perch (*Sebastodes alutus*)	1–2 kGy	25-28 days at 0.6 °C	Reinacher and Ehlermann, 1978
Herring (*Clupea herring*)	1–2 kGy	10-14 days at 2°C	Snauwert et al., 1977
Whitefish (*Coregonus clupeaformis*)	1.5–3 kGy	15–29 days, under refrigeration.	Arvanitoyannis et al., 2009
European hake (*Merluccius merluccius*)	1-1,5 kGy,	24–28 days at 0.5 °C.	Arvanitoyannis et al., 2009
Mackerel (*Rastrellinger kanagurta*)	1.5 kGy	21–24 days at 0°C, 13–15 days at 5°C and 7–11 days at 7.8°C.	Arvanitoyannis et al., 2009
Mackerel (*Scomber scombrus*)	*2.5* kGy	30–35 days at 0.6 °C	Arvanitoyannis et al., 2009
White pomfret (*Stomateus cinereus*)	1 kGy	4 week at 0-2°C	Arvanitoyannis et al., 2009
Black pomfret (*Parastomatus niger*)	1 kGy	10-16 days at 0-2°C	Arvanitoyannis et al., 2009
Sole (*Parophyrs vetulus*)	2-3 kGy,	4-5 weeks	Arvanitoyannis et al., 2009
Grey sole (*Glyptocephalus cynoglossus*)	1-2 kGy	29 days at 0.6°C or 10–11 days at 5.6°C	Arvanitoyannis et al., 2009
Haddock fillets (*Melanogrammus aeglefinus*)	1,5-2,5 kGy	22–25 days at 5.6°C and 30–35 days at 0.6°C	Arvanitoyannis et al., 2009

Table 2: The shelf life of non-irradiated and irradiated sea foods

Seafood	Shelf life of non-irradiated samples	Dose	Shelf life	References
Yellow perch fillets (*Perca flavescens*)	10 day at 1°C 10 day at 1°C 6 day at 6°C	1-2 kGy 3-6 kGy 3-6 kGy	18 day at 1°C 43-55 day at 1°C 18-24 day at 1°C	Arvanitoyannis et al., 2009
Bombay duck (*Harpodon nehereus)*	5 day packaged in polyethylene pouches	2,5 kGy	packaged in polyethylene pouches 20-22 day at 0-2°C	Arvanitoyannis et al., 2009
Shucked surf clam meats (*Spisula solidissima*)	10 day air packed in plastic pouches at 0,6 °C	1-2 kGy	40 day air packed in plastic pouches at 0,6 °C	Arvanitoyannis, et al., 2009
Shucked surf clam meats (*Spisula solidissima*)	10 day air packed in plastic pouches at 0,6 °C	4,5 kGy	50 day air packed in plastic pouches at 0,6 °C	Arvanitoyannis et al., 2009
Shucked mussel meats	3 week air packed at 3 °C	1,5-2,5 kGy	6 week air packed at 3 °C	Arvanitoyannis et al., 2009
Cooked king crabmeat (*Paralithides camtschatica*)	5-9 day vacuum packed at 0,6 °C	2 kGy	35 day vacuum packed at 0,6 °C	Arvanitoyannis et al., 2009
Precooked crabmeat (*Portunus pelagicus*)	7 day air packed in plastic bags at 3 °C	2 kGy	28 day air packed in plastic bags at 3 °C	Arvanitoyannis et al., 2009
Norwegian lobster (*Nephrops norvegicus*) tails	4 week blanched at 0-1 °C	2-3 kGy	5-6 week blanched at 0-1 °C	Arvanitoyannis et al., 2009
Salted trout	7 day vacuum packaged	0,5-2 kGy	Vacuum packaged 18-28 days at 4°C	O'bryan et al., 2008
Salted sea bream	14-15 day in vacuum packaging	1-3 kGy	in vacuum packaging 27-28 days at 4°C	Chouliara et al., 2004
Atlantic horse mackerel (*Trachurus trachurus*)	8 day at 0-1°C	1-3 kGy	12 day at 0-1°C	Savvaidis et al., 2002
Threadfin bream (*Nemipterus japonicus*)	9 day packaged in polyethylene pouches and dipped in 10% (w/w) sodium chloride	1-2 kGy	packaged in polyethylene pouches and dipped in10% (w/w) sodium chloride 14 and 28 day in ice storage	Jeevanandam et al., 2001
Threadfin bream (*Nemipterus japonicus*)	8 day packaged in polyethylene pouches,	1-2 kGy	packaged in polyethylene pouches, 12 and 22 day in ice storage	Jeevanandam et al., 2001
Blue jack mackerel (*Trachurus picturatus*)	3-4 day at 3°C	1-2 kGy	8 day at 3°C	Mendes et al., 2000
Smoked salmon fillets	1 month under refrigeration	2-4 kGy	3-4 month under refrigeration	Lakshmanan et al., 1999
Eviscerated Indian Mackerel *Rastrelliger kanagurta*)	14 day in ice storage	1,5 kGy	20 day in ice storage	Lakshmanan et al., 1999
Nagli fish (*Sillago sihama*)	8 day at 1-2°C	2-3 kGy	19 day at 1-2°C	Ahmed et al., 1997
Whitefish (*Coregonus clupeaformis*)	7 day at 3°C	0,82-1,22 kGy	20-28 day at 1°C 17-21 day at 3°C	Chuaqui-Offermanns et al., 1988
Peeled European brown shrimp (*C. vulgaris* and *C. crangon*)	9-16 day at 2°C	1,5 kGy	23 day at 2°C	Vyncke et al., 1976
Bombay duck (*Harpodon nehereus)*	5-7 day under refrigeration	1,5-2,5	15-20 day under refrigeration	Kumta et al., 1970

Table 3. Application of high pressure treatment to improve the quality of seafood products

Seafood	High pressure condition	Effect	References
Rainbow trout	in combination with vacuum packaging 220 MPa for 15 min at 5 °C, kept in chilled (4±1 °C)	According to the chemical and microbiological shelf life analysis results of rainbow trout fillets, shelf life increases of 4 days.	Günlü et al., 2014
Shrimp (Black tiger shrimp)	Shrimp was high-pressure processed at selected pressure levels of 100, 270, and 435 MPa for 5 min at room temperature (25±2 °C).	The effect of high-pressure processing on quality and shelf life of black tiger shrimp was studied. Changes in physical, biochemical, and microbiological characteristics after processing and during subsequent chilled storage were examined for 35 days.	Kaur et al., 2013
Prawn	in combination with vacuum packaging 100, 270, 435, 600 MPa for 5 min at 25 °C, kept in chilled (2±1°C)	pH and TBA values increased after HP treatment and significantly increased on storage. Reduction of TMA and TVB-N values after HP treatment was observed and during storage there was a gradual increase in all samples. Hardness, whiteness (L* value) and yellowness (b* value) increased with increasing pressure and redness (a* value) was found to decrease.	Bindu et al., 2013
Smoked cod	in combination with vacuum packaging 400, 500 and 600 MPa for 5 and 10 min at 5°C	400 MPa for 10 min or 500 MPa for 5 min successfully to extend the refrigerated shelf life of smoked cod.	Montial et al., 2012
Red abalone	 control 500 MPa for 8 min at 20°C and 550 MPa for 3 and 5 min at 20°C	According to chemical parameters 9 day shelf- life 12 day shelf- life 12 day shelf- life	Briones-Labarca et al., 2012
Tuna	Yellow fin tuna chunks packed in ethyl vinyl alcohol (EVOH) films. Pressure treatments of 100, 200 and 300 MPa.	The K-value of tuna was found to decrease with increase in pressure. High pressure treatment showed a decrease in the bacterial load. 200 MPa treated tuna chunks was found most acceptable.	Kamalakanth et al., 2011
Herring (*Clupea harengus*)	in combination with vacuum packaging 200 MPa for 1 min at 2°C 200 MPa for 3 min at 2°C 250 MPa for 1 min at 2°C 250 MPa for 3 min at 2°C 300 MPa for 1 min at 2°C 300 MPa for 3 min at 2°C	Control 6 day shelf- life 11 day shelf- life 17 day shelf- life 13 day shelf- life 16 day shelf- life 18 day shelf- life 16 day shelf- life	Karim et al., 2011
Cold smoked salmon	control 250 MPa, 3 °C for 5 min and 250 MPa, 25 °C for 10 min	6 week shelf- life 8 week shelf- life 8 week shelf- life	Erkan et al., 2011
Sea bream	Control 250 MPa for 3 min and 5 °C 250 MPa for 3 min and 15°C	15 day shelf- life 18 day shelf- life 18 day shelf- life	Erkan and Üretener, 2010

Table 3. Continued

Seafood	High pressure condition	Effect	References
Red mullet	control 220 MPa for 5 min at 25 °C 330 MPa for 5 min at 3 °C.	12 days shelf- life 14 days shelf- life 15 days shelf- life	Erkan et al., 2010
Squid (*Todarodes pacificus*)	300 MPa for 20 min at 20°C	The inhibition of trimethylamine-N-oxide demethylase (TMAOase) activity and off-odour production in squid treated at 300 MPa for 20 min was investigated during 12 days of refrigerated storage. The number of total aerobic bacteria in squid was reduced by 1.26 log units after HP.	Gou et al., 2010
Coho salmon (*Oncorhynchus kisutch*) and abalone (*Haliotis rufescens*)	For salmon, HHP treatments were applied at 135, 170, and 200 MPa for 30 s, while abalone treatment consisted of 500 MPa for 8 min and 550 MPa for 3 or 5 min.	Results have shown that HHP treatment reduced the initial microbial counts of salmon from 3.16 to 2.2 log units, moreover abalone was reduced from 1.3 log to undetectable levels (<10 cfu/g). HHP-treatment used for salmon were not sufficient to extend their shelf-life. However, the shelf-life of abalone was extended from 30 (control samples) to >65 days irrespective of HHP treatment applied.	Briones et al., 2010
Oyster (*Crassostrea gigas*)	260, 400 or 600 MPa for 5 min at 20°C	HP treatment influenced the gross composition, microbiological composition and quality of oyster tissue compared to untreated oysters. This process also decreased microbial levels and extended the shelf-life of oysters	Cruz-Romero et al., 2008a
Oyster (*Crassostrea gigas*)	260 MPa for 3 min or 400 MPa for 5 min at 20°C	HP treatment, in combination with adequate chilled storage and MAP, extend the shelf-life of oysters.	Cruz-Romero et al., 2008b
Cold-smoked dolphinfish (*Coryphaena hippurus*)	300 MPa for 15 min at 20°C	In microbiological terms, high pressure did not prolong the shelf life though it did achieve better microbiological quality during chilled storage sensory quality was preserved	Gómez-Estaca et al., 2007b

Table 3. Continued

Seafood	High pressure condition	Effect	References
Mahi mahi and Rainbow trout	300-450-600 MPa for 15 min 6 °C	300 MPa for rainbow trout and 450 MPa for mahi mahi are the optimum HPP conditions for controlling microbial load, lipid oxidation, and colour changes.	Yağız et al., 2007
Albacore tuna	275 and 310 MPa for 2, 4, and 6 min	Pressure improved the shelf life of albacore muscle for > 22 days at 4 °C. control samples 5 day	Ramirez-Suarez et al., 2006
Tuna	150 MPa, 200 MPa, 220 MPa, holding times (30 min, 15 min) at 20 °C	Lower microbiological counts	Zare, 2004
Hake (*Merluccius capensis*)	400 MPa (three 5-min cycles) at 7 °C stored at 3°C	The microbial load was initially reduced by two log units by pressurization 400 MPa. Shelf life was prolonged by about one week in the lot pressurized at 200 MPa and about two weeks in the lot 400 MPa.	Hurtado et al., 2000
Fresh Atlantic salmon	High pressure HP processing at low temperatures combined with modified atmosphere packaging (MA)	A shelf life extension of 2 days was obtained after a HP treatment of 150 MPa for 10 min at 5 °C compared to unpressurised, vacuum-packed salmon. MA storage (50% O_2 -50% CO_2) alone extended the shelf life of salmon for 4 days at 5 °C.	Amanatidou et al., 2000
Cod (*Gadus morhua*)	0, 200, 400, 600 and 800 MPa for 20 min)	After treatment at pressures above 400 MPa, the oxidative stability of the lipids in cod muscle were markedly decreased as measured by the thiobarbituric acid (TBA) number.	Angsupanich and Ledward, 1998

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