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Effect of High Pressure Processing on the Quality of Chilled Stored Grass Carp (*Ctenopharyngodon idella*) Fillet*

YAKHIN Lisa Amanda[1], ZHANG Li-Li[1], WANG Yuan-Liang[1,2], LI Zong-Jun[1]

(1. *College of Food Science and Technology, Hunan Agricultural University, Changsha* 410128, *China*;
2. *Hunan Province Key Laboratory of Food Science and Biotechnology, Changsha* 410128, *China*)

Abstract: This study is aimed to observe the effect of different pressure (300, 400, 500 MPa) and different pressure holding time (5, 10, 15 min) on vacuum packed grass carp fillet. The fillets were stored at chilling temperature (4 ℃) for 15 d, and the observations were carried out every 3 d. The electron micrographs showed that there were modifications on longitudinal sections (sarcomere disorganization) of muscle fiber treated by high pressure for 5 min. The *K*-values of fish fillets treated by 400 and 500 MPa were below 70%, and they were still considered fresh at least until 6 and 12 d, respectively. Therefore, the application of high pressure processing was able to improve the shelf life of grass carp fillets. However, the application of high pressure treatment reduced the water holding capacity and increased the hardness of fish meat. In addition, the values of L^*, a^* and b^* were all increased with the increase of storage time, and both L^* and b^* were increased with pressure, while a^* was reduced with pressure.

Key words: high pressure; ultrastructure; *K*-value; color; water holding capacity; texture

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1 Introduction

In human nutrition, fish and fish products play an important role as a source of biologically valuable proteins, fats and fat-soluble vitamins. Grass carp (*Ctenopharyngodon idella*), a freshwater fish from Cyprinidae family, is a type of fish commonly cultivated in China for food.

Fresh fish has *K*-value less than 50%, high water holding capacity (WHC) and white color. Compared to the fresh fish, the muscle fibers of the fish after storage are not firmly bundled anymore, thus it has low WHC. Stale fish also has high *K*-value, grayish, yellowish, and reddish meat as low quality.

The two main causes of fish spoilage are action of endogenous enzymes autolysis and bacterial spoilage[1-2]. Nowadays, preservation techniques are not only aimed at preserving foods, but also focus for keeping the intrinsic nutrition and sensory qualities. High pressure processing (HPP) is an emerging non-thermal technology for food preservation that retains the essential function, flavor, and nutrition of food products. In animal tissue muscle, HPP is used for preservation[3-8] and texturation[8-13].

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Biography: YAKHIN Lisa Amanda(1986—), female, master, major in food science. E-mail: layakhin@gmail.com

Corresponding Author: LI Zong-Jun(1967—), male, Ph. D., professor, major in food science. E-mail: lizongjun@yahoo.com.cn

It is known that HPP brings some changes related to the texture and WHC of fish through denaturing the protein components[12,14]. For example, the toughness of Norway lobster increased when subjected to pressurization (200 MPa, 50 ℃) or high-pressure shift freezing (200 MPa, −18 ℃)[15].

The color is gradually changed by either the increase of the pressure level or extending the holding time. A study carried out showed that pressure-shift frozen (PSF) turbot obtained an increase in L^* ($L^*=0$ yields black and $L^*=100$ indicates diffuse white) value, known as the whitening effect[15]. This whitening effect is also found in pressurized turbot fillets[5], carp[16-17], and minced sardine meat[18]. It has also been reported that a^* (a^*, negative values indicate green while positive values indicate magenta) values of mackerel and cod fish decrease after pressurization[19-21], while b^* (b^*, negative values indicate blue and positive values indicate yellow) values increase with increasing of pressure and holding time[5,15-16].

The objective of this research is to analyze the effects of pressure and holding time on the physical and chemical quality of vacuum-packed grass carp fillet stored at chilling temperature of 4 ℃.

2　Materials and Method

2.1　Fish

Fresh grass carp fish with similar size ((3.0±0.2)kg each) were obtained from the local market at Hunan Agricultural University. The fish was immediately gutted, cleaned, filleted ((120 ± 20) g each) and vacuum packed within 2 h. Then, the vacuum packed fish fillets were stored at 4 ℃.

2.2　High Hydrostatic Pressure Treatment

HPP of vacuum packed grass carp fillet was carried out in a designed and constructed lab-scale high-pressure system (High Pressure PATS Equipment, HHP-700-6, developed by China Agricultural University) at College of Food Science and Nutritional Engineering, China Agricultural University. The maximum design pressure of the system is 700 MPa at an ambient operating temperature of 25 ℃. Vacuum packed grass carp fillet samples were treated at 300, 400, and 500 MPa for 5, 10 and 15 min. Observations and analysis were done every 3 d during 15 d, including K-value, WHC, color and texture profile.

2.3　K-Value Analysis[21]

K-value is used as an indication for the freshness of fish. The K-value indicates the level of ATP (Adenosine Triphosphate) degradation. 5 g of fish muscle was ground and homogenized for 1 min with 25 mL of chilled 0.6 mol/L perchloric acid at 0 ℃. Samples were subsequently centrifuged for 10 min in 6 000 r/min. The decantate was neutralized with 1 mol/L KOH to pH 6.5-6.8 and placed in a 2 ℃ freezer for 30 min for precipitation. The precipitated potassium perchlorate was filtered (0.45 μm), diluted to 20 mL and stored at −80 ℃ until analysis. 20 μL of samples were injected into a Agilent-1100 HPLC (High Performance Liquid Chromatography) instrument equipped with a 5 μm column (250 mm×4.6 mm, Thermo Scientific) at 30 ℃. The mobile phases used were 0.04 mol/L potassium dihydrogen phosphate and 0.06 mol/L dipotassium hydrogen phosphate, with the flow rate of 2 mL/min. Detection was done at 254 nm UV.

The K-value was calculated as follows

$$K=\frac{w_{\mathrm{Ino}}+w_{\mathrm{Hx}}}{w_{\mathrm{ATP}}+w_{\mathrm{ADP}}+w_{\mathrm{AMP}}+w_{\mathrm{IMP}}+w_{\mathrm{Ino}}+w_{\mathrm{Hx}}}\times 100\% \tag{1}$$

where w_{ATP}, w_{ADP}, w_{AMP}, w_{IMP}, w_{Ino} and w_{Hx} are mass fractions of ATP and its degradation products ADP (Adenosine Diphosphate), AMP (Adenosine Monophosphate), IMP (Inosine Monophosphate),

Ino (Inosine) and Hx (Hypoxanthine) respectively.

2.4 Ultra-Structure Observation

Samples (0.3 cm×0.3 cm) were cut and sent to Institute of Life Sciences, Hunan Normal University for Transmission Electron Microscopy observation (80 kV, JEOL-1230). The longitudinal sections of muscle fiber were observed to characterize the modifications of myofibrils induced by high pressure treatment.

2.5 WHC Analysis[22]

5 g of fish meat, wrapped by filter paper, was centrifuged at 500 g (or 800 r/min), 10 ℃ for 10 min (Hitachi CF16RXII, Japan). WHC is expressed as the total water retained divided by the total initial water content.

2.6 Color Analysis

The color of fish meat (4 cm×4 cm) was tested by $L^* a^* b^*$ color system (BOIF Colorimeter 5003/WSC-Y, Beijing Optics Instrument, China). The $L^* a^* b^*$ color system is a color-opponent space with dimension L for lightness and a and b for the color-opponent dimensions, based on nonlinearly compressed CIE XYZ color space coordinates.

2.7 Texture Profile Analysis

Texture profile analysis (TPA) was carried out in order to know the effect of pressure on the mechanical properties related to the sensory properties of human. P/50 cylindrical probe was assembled to the TA-XT plus texture analyzer. The computer software (Exponent Stable Micro System V5) was set to plot a force versus time plot. Test was performed on fillet samples with a size of 1.5 cm×1.5 cm×1.5 cm. Each sample was measured six times. Two cycles of compression were performed to reach 50% of their original heights at a speed of 2 mm/s. Two parameters were then calculated: the hardness and chewiness. Hardness is the peak force of the first compression cycle, while chewiness is the energy required to masticate solid food to a state of readiness for swallowing, obtained from the calculation of hardness, cohesiveness and springiness.

2.8 Statistical Test

Analysis of variance (ANOVA) was carried out by SPSS 16.0 statistical program (SPSS Inc., Chicago, USA). Multiple comparisons were performed using the Tukey test ($P<0.05$).

3 Results and Discussion

3.1 Effect of HPP on K-value

As a parameter to determine the freshness of fish, K-value is shown to be significantly affected by storage time and pressure applied, but not by the pressure holding time. The effect of pressure on K-value can be seen in Fig. 1.

The increasing rates of K-value are reduced by the increase of the treatment pressure. The same result is also obtained in tilapia fillet during high-pressure storage (100-300 MPa, 25 ℃, 2-12 h)[23]. High pressure

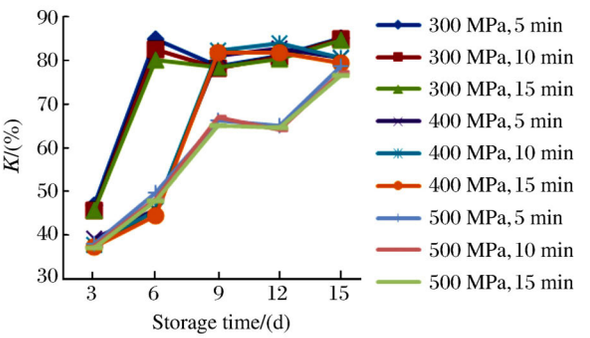


Fig. 1 Effect of pressure on K-value for the muscle of grass carp fillet stored at 4 ℃

above 200 MPa leads to irreversible protein denaturation[3,5], thus the high pressure may inactivate the enzymes. Inactivation of phosphatase is obtained during 600 MPa treatment at 55 ℃[24]. High pressure reduces holothurians auto-enzyme activity to 88.25% after pressurization (200 MPa, 20 min, room temperature) and reaches the lowest level of 29.81% at 550 MPa[25]. Papain enzyme activity also decreases to 90.04% after 180 MPa dynamic high pressure microfluidization treatment[26]. Other researchers also found the inactivation of exoproteinase of *Bacillus subtilis*, which is correlated with its lethal rate[27].

The fish products with the *K*-value higher than 70% are considered as stale[28]. After 3 d of storage, the *K*-values of grass carp fillet by 300, 400 and 500 MPa treatment are 46.68%, 38.14% and 37.51%, respectively, indicating that HPP has the ability to lengthen the shelf life of grass carp fillet meat at least 3 d for 300 MPa, 6 d for 400 MPa, and 12 d for 500 MPa. Compared to the results of microbiological testing, it is also found that the total aerobic plate count is below 7 lg(CFU/g) for treatment of 500 MPa, after 7 d of storage[14]. HPP is an effective approach to reduce the microbial growth and improve the shelf life of fish.

3.2　Effect of HPP on Ultrastructure

The fresh sample shows normal alignment of sarcomeres and normal ultrastructure of thick and thin filaments. Fresh muscle has a standard ultrastructure of sarcomeres built from the *z*-line, light I-band and dark A-band, as shown in Fig. 2. All high pressure treatments (300-500 MPa, 5 min) disorganize the alignment of sarcomeres (Fig. 3). After 300 MPa, the sarcomeres are contracted, and the thick and thin filaments are aggregated. After 400 and 500 MPa, the sarcomeres are totally disrupted, and no thick or thin filament can be observed clearly anymore.

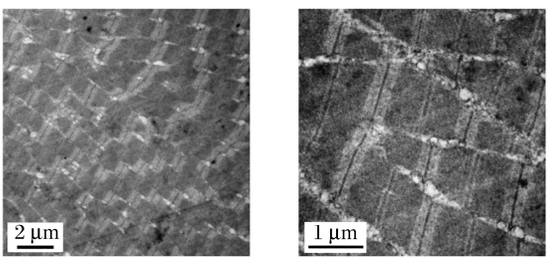
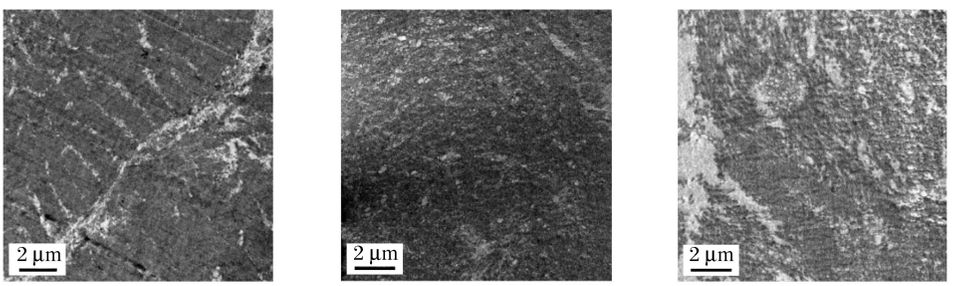


Fig. 2　Ultrastructure of the fresh grass carp muscle sample



(a) 300 MPa, 5 min　(b) 400 MPa, 5 min　(c) 500 MPa, 5 min

Fig. 3　Ultrastructure of pressurized grass carp muscle samples

For *post-rigor* steaks of *Biceps femoris* muscles (2 d post-mortem) pressurized at 520 MPa, the myofibrillar cross section are completely modified, the myofibrils appear as indistinguishable shapes, and the myofilaments appear to be dissociated[29]. The effect of high pressure treatment on the ultrastructure of grass carp fillets is considerable and significant, especially at higher pressure.

3.3　Effect of HPP on WHC

The effect of HPP on WHC of grass carp fillet is shown in Fig. 4. WHC of grass carp fillet decreases due to the pressurization and storage. The initial WHC of fresh grass carp fillet is 89.903%, which

is much higher than that of pressurized grass carp fillet.

High pressure processing results in some changes related to the texture and WHC of the fish through denaturing protein components[19]. Above 200 MPa, the oligomeric structure of proteins dissociation are induced, and partial unfolding as well as denaturation of monomeric structures, protein aggregation and gelation also take place[30-32]. These facts explain the decrease of WHC after pressurization.

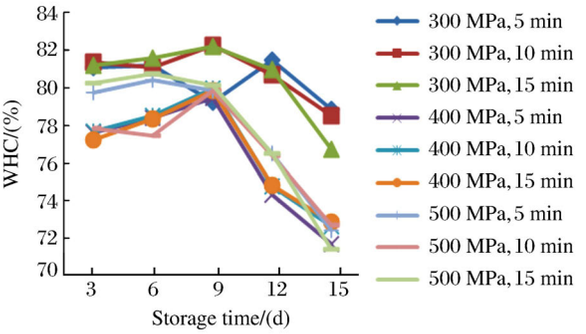


Fig. 4 Effect of high pressure on WHC of grass carp fillet stored at 4 ℃

A decrease of WHC is also observed in all pressure levels (100-200 MPa, 10-20 min, room temperature) for fresh, cold smoked salmon[12] and sea bass fillets (100-500 MPa, 5 min, 10 ℃)[14].

3.4 Effect of HPP on Texture Profile

The texture profile analysis results indicate that the hardness and chewiness are all affected by the high pressure treatment. Generally the hardness and chewiness of the fish are gradually increased as the increase of pressure and gradually decreased with the storage time. The results show that there are no significant differences of hardness and chewiness in different holding pressure time. The effect of high pressure on the texture profile can be seen in Fig. 5.

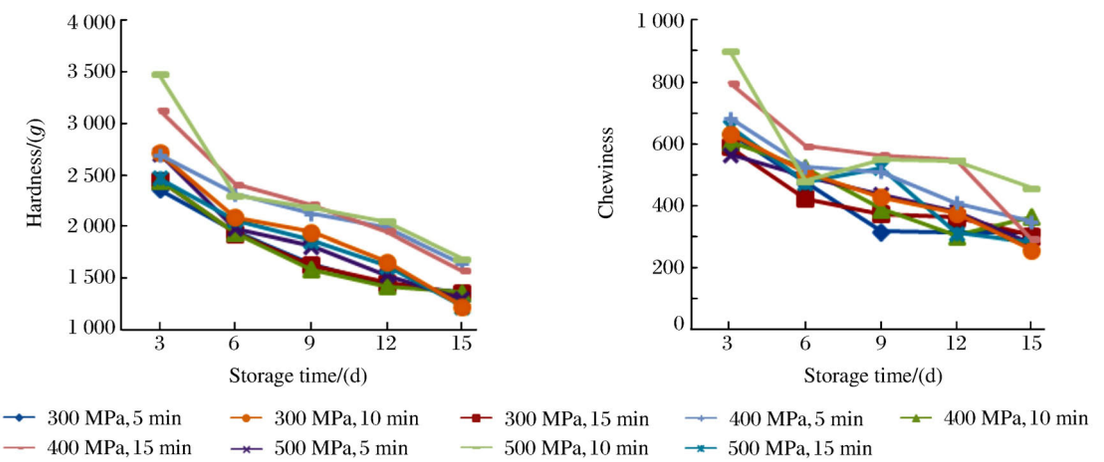


Fig. 5 Effect of high pressure on hardness and chewiness of grass carp fillet stored at 4 ℃

High pressure treated thawed Atlantic salmon fillets (100-200 MPa, 20 ℃), as well as salmon, whiting, haddock, cod and rainbow trout (200 MPa, room temperature, 60 min) has a tougher texture compared to the atmospheric pressure[7,33]. The increase of hardness after pressurization is also found in Norway lobster[15], cod[3], cold smoked salmon[30], turbot[34], beef and pork[35].

During storage, a decrease in hardness and chewiness are observed. Softening of fish muscle is commonly caused by enzymatic degradation of myofibrils and collagen, as well as physical separation of myotomes called gaping. The application of high pressure treatment increases the hardness of fish after storage, thus it kept the hardness in an acceptable range, not to be rejected as soft fish[14].

The changes of texture profile are also related to protein denaturation[15] as well as coagulation, stiffening and aggregation of myofibrillar structure[34-35]. The undesirable hardening following high-

pressure treatment may be reversed by subsequent cooking[36].

3.5 Effect of HPP on Color

In high pressure treatment, discoloration is one of the results that have been widely observed[37]. The initial values of L^*, a^* and b^* are 36.72±1.20, 4.23±1.98 and −3.12±0.56, respectively. The change of color is shown in Table 1. It can be seen that the values of L^*, a^* and b^* all increase with the increase of storage time, and both L^* and b^* increase with pressure, while a^* reduces with pressure.

Table 1　The effect of high pressure on color of grass carp fillet stored at 4 ℃

Pressure /(MPa)	t /(min)	Storage time/(d)	Color parameters			Pressure /(MPa)	t /(min)	Storage time/(d)	Color parameters		
			L^*	a^*	b^*				L^*	a^*	b^*
300	5	3	39.66 ± 0.92^{a}	4.69 ± 0.50^{a}	-3.48 ± 0.20^{a}	400	15	3	55.70 ± 0.98^{j}	2.78 ± 0.65^{cm}	-2.47 ± 0.33^{e}
		6	39.08 ± 0.88^{a}	5.38 ± 0.83^{ab}	1.45 ± 0.34^{b}			6	55.54 ± 0.99^{j}	3.41 ± 1.55^{cdn}	2.31 ± 0.23^{f}
		9	40.42 ± 1.19^{b}	5.01 ± 0.50^{b}	2.51 ± 0.26^{c}			9	57.42 ± 1.15^{k}	3.60 ± 0.29^{deo}	3.58 ± 0.47^{g}
		12	41.18 ± 1.73^{b}	5.27 ± 0.45^{b}	2.68 ± 0.19^{cd}			12	57.55 ± 0.45^{k}	4.46 ± 0.38^{e}	3.58 ± 0.48^{gh}
		15	41.51 ± 1.37^{c}	5.49 ± 1.18^{b}	2.80 ± 0.64^{d}			15	58.52 ± 0.72^{l}	4.70 ± 0.94^{ep}	3.94 ± 0.82^{h}
300	10	3	39.61 ± 0.27^{d}	4.15 ± 0.56^{a}	-3.39 ± 0.87^{a}	500	5	3	55.22 ± 0.95^{g}	3.00 ± 0.89^{fm}	-1.71 ± 0.46^{i}
		6	39.56 ± 1.96^{d}	4.95 ± 0.95^{ab}	1.53 ± 0.37^{b}			6	56.19 ± 0.42^{g}	3.56 ± 1.62^{fn}	3.41 ± 0.58^{j}
		9	41.41 ± 0.28^{e}	5.06 ± 0.59^{b}	2.22 ± 0.81^{c}			9	56.12 ± 2.03^{h}	3.75 ± 0.69^{fo}	4.33 ± 0.81^{k}
		12	41.71 ± 0.22^{e}	5.17 ± 0.55^{b}	2.79 ± 0.63^{cd}			12	57.13 ± 1.00^{h}	3.66 ± 1.10^{f}	4.52 ± 0.41^{kl}
		15	42.62 ± 0.67^{f}	5.43 ± 0.30^{b}	2.85 ± 0.76^{d}			15	57.95 ± 1.05^{i}	4.90 ± 0.73^{gp}	4.76 ± 1.04^{l}
300	15	3	39.95 ± 0.33^{d}	4.64 ± 0.62^{a}	-3.47 ± 0.33^{a}	500	10	3	55.67 ± 0.35^{j}	3.55 ± 1.30^{fm}	-1.62 ± 0.36^{i}
		6	39.75 ± 1.46^{d}	4.80 ± 0.51^{ab}	1.59 ± 0.33^{b}			6	55.68 ± 0.50^{j}	3.54 ± 0.35^{fn}	3.44 ± 0.48^{j}
		9	41.14 ± 0.74^{e}	5.06 ± 0.77^{b}	2.27 ± 1.72^{c}			9	56.77 ± 0.58^{k}	3.18 ± 0.58^{fo}	4.40 ± 0.64^{k}
		12	41.36 ± 0.82^{e}	5.55 ± 1.07^{b}	2.72 ± 0.32^{cd}			12	56.96 ± 0.40^{k}	3.23 ± 0.35^{f}	4.18 ± 0.36^{kl}
		15	42.27 ± 0.87^{f}	5.76 ± 0.42^{b}	2.92 ± 0.73^{d}			15	57.72 ± 0.46^{l}	4.46 ± 0.89^{gp}	4.76 ± 0.41^{l}
400	5	3	55.35 ± 2.41^{g}	2.76 ± 0.21^{cm}	-2.15 ± 1.22^{e}	500	15	3	55.20 ± 0.68^{j}	3.66 ± 0.27^{fm}	-1.38 ± 1.19^{i}
		6	55.27 ± 1.36^{g}	3.06 ± 1.26^{cdn}	2.64 ± 1.20^{f}			6	55.86 ± 0.76^{j}	3.61 ± 0.30^{fn}	3.75 ± 0.66^{j}
		9	56.56 ± 0.30^{h}	3.97 ± 0.64^{deo}	3.47 ± 0.75^{g}			9	56.77 ± 0.55^{k}	3.42 ± 0.60^{fo}	4.04 ± 1.16^{k}
		12	57.14 ± 2.59^{h}	4.19 ± 0.20^{e}	3.63 ± 0.66^{gh}			12	57.27 ± 0.55^{k}	3.94 ± 0.43^{f}	4.38 ± 0.26^{kl}
		15	56.55 ± 0.94^{i}	4.18 ± 1.02^{ep}	3.79 ± 0.84^{h}			15	57.82 ± 0.71^{l}	4.51 ± 1.50^{gp}	4.62 ± 0.61^{l}
400	10	3	55.64 ± 0.73^{j}	3.08 ± 1.54^{cm}	-2.34 ± 0.29^{e}						
		6	55.56 ± 0.75^{j}	3.00 ± 0.44^{cdn}	2.68 ± 0.46^{f}						
		9	57.06 ± 1.04^{k}	3.62 ± 1.05^{deo}	3.50 ± 0.25^{g}						
		12	57.19 ± 0.11^{k}	3.88 ± 0.34^{e}	3.52 ± 1.14^{gh}						
		15	58.06 ± 1.01^{l}	4.20 ± 1.50^{ep}	3.88 ± 0.47^{h}						

Note: t represents pressure holding time, and different letters (a, b, c, d, e, f, g, h, i, j, k and l) in the same column indicate significant differences ($P<0.05$).

The immediate effect of HPP on lightness can be visually observed (appeared as cooked). L^* values increase when higher pressure and longer storage time are applied. A similar effect is also observed in turbot fillets[5], PSF treated turbot fillets[34], sea bass[14], and oyster[13]. Immediate effect on the lightness is noticed in cold smoked salmon even in a very short holding time (400-900 MPa, 10-60 s)[29]. The whitening effect is related to the denaturation of the myofibrillar and sarcoplasmic proteins[37]. Gradual disintegration of myofibrils during spoilage gives rise to a wider and more random intracellular distribution, resulting in unevenly scattered light and opaque appearance[38].

Compared to 300 MPa, a^* value is lower at higher pressure of 400 and 500 MPa. It is suggested that pressure-induced coagulation of sarcoplasmic and myofibrillar proteins are possibly responsible for

the observed changes in a^* values[37,39]. The decrease of a^* values resulted by the increase of pressure has also been reported in other seafood[40], including mackerel[19], salmon[41], raw cod[20], and PSF turbot[34].

With respect to the storage time and pressure applied, a significant increase of b^* value indicates that the fish fillets are more yellow after pressurization and storage. The same results are also presented in some other studies[5,7,30,34]. The color change in fish meat is closely related to the lipid and carotenoid pigment oxidation[3,38]. Lipid oxidation is observed at turbot fillets after high pressure-low temperature treatment[5].

Changes in color may limit the use of HPP treatment, but because the changes by HPP are similar to that by heat treatment, high pressure application can still be considered. After heat treatment, the effect of pressure in cooked-fish fillets is not as high as the uncooked ones. Uncooked pressurized fish product has bigger color difference compared to uncooked untreated fish product[33].

4 Conclusions

HPP conducted at room temperature is able to delay the spoilage and improve the texture quality of grass carp meat. Color changes (appeared as cooked) may limit the application of HPP in fresh fish, but this change is inconsiderable after being cooked. High pressure treatment reduces the WHC and increases the toughness of fish meat.

Changes in texture and color of fish fillet have particular significance for seafood which is not cooked prior to consumption. A research to observe the effect of high pressure treatment after cooking in fish and its effect to consumer acceptance is required to broaden the application of HPP in fish products. There is a new development in HPP technology which enables the high pressure to be reached in few seconds; this development may reduce the undesirable changes. Decreasing the working temperature during treatment will likely reduce the changes of color and texture, thus the effect of HPP is improved to prolong the shelf life of grass carp fish.

References:

[1] Nollet L M. Handbook of Meat, Poultry and Seafood Quality [M]. Iowa, USA: Blackwell Publishing, 2007: 577-585.

[2] Torry Research Station, Ministry of Agriculture. Fisheries and food. Quick freezing of fish [EB/OL]. (2011-10-08) http://www.fao.org/wairdℂs/tan/x5906e/x5906e00.htm.

[3] Angsupanich K, Ledward D A. High pressure treatment effects on cod (*Gadus morhua*) muscle [J]. Food Chem, 1998, 63(1): 39-50.

[4] Boskou G, Debevere J. Shelf-life extension of cod fillets with an acetate buffer spray prior to packaging under modified atmospheres [J]. Food Addit Contam, 2000, 17(1): 17-25.

[5] Chevalier D, LeBail A, Ghoul M. Effects of high pressure treatment (100-200 MPa) at low temperature on turbot (*Scophthalmus maximus*) muscle [J]. Food Res Int, 2001, 34(5): 425-429.

[6] Yaldagard M, Mortazavi S A, Tabatabaie F. The principles of ultra high pressure technology and its application in food processing/preservation: A review of microbiological and quality aspects [J]. Afr J Biotechnol, 2008, 7(16): 2739-2767.

[7] Zhu S, Ramaswamy H S, Simpson B K. Effect of high-pressure versus conventional thawing on color, drip loss and texture of Atlantic salmon frozen by different methods [J]. LWT-Food Sci Tech, 2004, 37(3): 291-299.

[8] Balny C, Masson P. Effects of high-pressure on proteins [J]. Food Rev Int, 1993, 9(4): 611-628.

[9] Chevalier D,LeBail A,Chourot J M,et al. High pressure thawing of fish (whiting):Influence of the process parameters on drip losses [J]. LWT-Food Sci Tech,1999,32(1):25-31.

[10] Chevalier D,Sequeira-Munoz A,LeBail A,et al. Effect of freezing conditions and storage on ice crystal and drip volume in turbot (*Scophthalmus maximus*):Evaluation of pressure shift freezing vs. air-blast freezing [J]. Innovat Food Sci Emerg Tech,2000,1(3):193-201.

[11] LeBail A,Chevalier D,Mussa D M,et al. High pressure freezing and thawing of foods:A review Congélation et décongélation de produits alimentaires sous haute pression [J]. Int J Refrig,2002,25(5):504-513.

[12] Lakshmanan R,Parkinson J A,Piggott J R. High-pressure processing and water-holding capacity of fresh and cold-smoked salmon (*Salmo salar*) [J]. LWT-Food Sci Tech,2007,40(3):544-551.

[13] Cruz-Romero M,Smiddy M,Hill C,et al. Effects of high pressure treatment on physicochemical characteristics of fresh oysters (*Crassostrea gigas*) [J]. Innovat Food Sci Emerg Tech,2004,5(2):161-169.

[14] Cheret R,Chapleau N,Delbarre-Ladrat C,et al. Effects of high pressure on texture and microstructure of sea bass (*Dicentrarchus labrax L.*) fillets [J]. J Food Sci,2005,70(8):477-483.

[15] Chevalier D,Sentissi M,Havet M,et al. Comparison of air-blast and pressure shift freezing on norway lobster quality [J]. J Food Sci,2000,65(2):329-333.

[16] Yoshioka K,Yamada A,Maki T. Application of high pressurization to fish meat:Changes in the physical properties of carp skeletal muscle resulting from high pressure thawing [J]. Prog Biotechnol,1996,13:369-374.

[17] Sequeira-Munoz A,Chevalier D,LeBail A,et al. Physicochemical changes induced in carp (*Cyprinus carpio*) fillets by high pressure processing at low temperature [J]. Innovat Food Sci Emerg Tech,2006,7(1/2):13-18.

[18] Balny C,Hayashi R,Heremans K,et al. High Pressure and Biotechnology [M]. Australia:John Libbey & Co. Ltd,1992:235-238.

[19] Ohshima T,Ushio H,Koizumi C. High-pressure processing of fish and fish products [J]. Trends Food Sci Tech,1993,4(11):370-375.

[20] Angsupanich K,Edde M,Ledward D A. Effects of high pressure on the myofibrillar proteins of cod and turkey muscle [J]. J Agric Food Chem,1999,47(1):92-99.

[21] Sallam K I. Chemical,sensory and shelf life evaluation of sliced salmon treated with salts of organic acids [J]. Food Chem,2007,101(2):592-600.

[22] Gunenc A. Evaluation of pork meat quality by using water holding capacity and vis-spectroscopy [D]. Montreal,Quebec,Canada:McGill University,2007.

[23] Ko W C,Hsu K C. Changes in *K* value and microorganisms of tilapia fillet during storage at high-pressure,normal temperature [J]. J. Food Prot,2001,64(1):94-98.

[24] Seyderhelm I,Boguslawski S,Michaelis G,et al. Pressure induced inactivation of selected food enzymes [J]. J Food Sci,1996,61(2):308-310.

[25] Xia Y J,Liu Z J,Li N,et al. Effects of high hydrostatic pressure treatment on holothurians autoenzyme activity [J]. Chinese Journal of High Pressure Physics,2009,23(5):377-383. (in Chinese)
夏远景,刘志军,李　宁,等. 超高压处理对海参自溶酶活性影响的研究 [J]. 高压物理学报,2009,23(5):377-383.

[26] Liu W,Zhong Y J,Liu C M,et al. The effect of dynamic high pressure microfluidization on the activity of papain [J]. Chinese Journal of High Pressure Physics,2010,24(2):129-135. (in Chinese)
刘　伟,钟业俊,刘成梅,等. 动态高压微射流技术对木瓜蛋白酶活性的影响 [J]. 高压物理学报,2010,24(2):129-135.

[27] Xie H M,Huang X D,Pan J,et al. Effect of high pressure on exoproteinase of *Bacillus subtilis* [J]. Chinese Journal of High Pressure Physics,2007,21(1):95-102. (in Chinese)
谢慧明,黄训端,潘　见,等. 超高压对枯草杆菌胞外蛋白酶的影响 [J]. 高压物理学报,2007,21(1):95-102.

[28] Saito T,Arai K,Matsuyoshi M. A new method for estimating the freshness of fish [J]. Bull Jpn Soc Sci Fish,1959,24(9):749-750.

[29] Jung S,Lamballerie-Anton M,Ghoul M. Modifications of ultrastructure and myofibrillar proteins of *post-rigor* beef treated by high pressure [J]. LWT-Food Sci Tech,2000,33(4):313-319.

[30] Gudbjornsdottir B,Jonsson A,Hafsteinsson H,et al. Effect of high-pressure processing on *Listeria* spp. and on the

textural and microstructural properties of cold smoked salmon [J]. LWT-Food Sci Tech, 2010, 43(2): 366-374.

[31] Damodaran S, Paraf M. Fundamentals of Food Proteins and Their Applications [M]. New York, USA: Marcel Dekker, 1997: 473-502.

[32] Mozhaev V V, Heremans K, Frank J, et al. High pressure effects on protein structure and function [J]. Proteins, 1996, 24(1): 81-91.

[33] Schubring R, Meyer C, Schluter O, et al. Impact of high pressure assisted thawing on the quality of fillets from various fish species [J]. Innovat Food Sci Emerg Tech, 2003, 4(3): 257-267.

[34] Chevalier D, Sequeira-Munoz A, LeBail A, et al. Effect of pressure shift freezing, air-blast freezing and storage on some biochemical and physical properties of turbot (*Scophthalmus maximus*) [J]. LWT-Food Sci Tech, 2000, 33(8): 570-577.

[35] Jung S, Ghoul M, de Lamballerie-Anton M. Changes in lysosomal enzyme activities and shear values of high pressure treated meat during ageing [J]. Meat Sci, 2000, 56(3): 239-246.

[36] Cheftel J C, Culioli J. Effects of high pressure on meat: A review [J]. Meat Sci, 1997, 46(3): 211-236.

[37] Autio K. Fresh Novel Foods by High Pressure [M]. Espoo, Finland: VTT Biotechnology and Food Research, 1998: 165-175.

[38] Charalambous G. Shelf Life Studies of Foods and Beverages: Chemical, Biological, Physical and Nutritional Aspects [M]. Amsterdam: Elsevier Science Publishers, 1993.

[39] Colmenero F J, Carballo J, Fernandez P, et al. High-pressure-induced changes in the characteristics of low-fat and high-fat sausages [J]. J Sci Food Agr, 1997, 75(1): 61-66.

[40] Shahidi F, Ho C T, van Chuyen N. Process-Induced Chemical Changes in Food [M]. New York, USA: Plenum Press, 1998: 67-78.

[41] Amanatidou A, Schluter O, Lemkau K, et al. Effect of combined application of high pressure treatment and modified atmospheres on the shelf life of fresh Atlantic salmon [J]. Innovat Food Sci Emerg Tech, 2000, 1(2): 87-98.

超高压处理对草鱼片的影响

YAKHIN Lisa Amanda[1], 张丽丽[1], 王远亮[1,2], 李宗军[1]

(1. 湖南农业大学食品科技学院, 湖南长沙 410128;
2. 湖南省食品科学与生物技术重点实验室, 湖南长沙 410128)

摘要: 实验研究了不同超高压(300、400 和 500 MPa)和不同处理时间(5、10 和 15 min)对真空包装草鱼片的影响, 其中草鱼片在 4 ℃下贮藏, 每隔 3 d 检测 1 次, 共贮藏 15 d。电子显微镜观察结果表明: 高压处理 5 min 后, 所有草鱼片肌肉纤维的纵向都发生了变化, 且采用超高压处理后, 货架期显著延长。对于经过 400 和 500 MPa 处理的草鱼片, 其 K 值降低了 70%, 保鲜期分别为 6 d 和 12 d。但是, 超高压处理降低了草鱼肉的持水力, 使鱼肉变硬。随着贮藏时间的延长, 高压处理后的草鱼肉的 L^*、a^* 和 b^* 值均升高, 且 L^* 和 b^* 与处理压力呈正相关, 而 a^* 值则相反。

关键词: 高压; 微观结构; K 值; 色泽; 持水力; 组织结构

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