Effect of different drying methods on the protein and product quality from hairtail fish meat gel

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ABSTRACT

Three different methods, namely hot air drying (HA), microwave vacuum drying (MV), and vacuum freeze drying (FD) were employed to investigate the effect of drying method on the quality of hairtail fish meat gel. Compared with HA and MV, FD samples showed a better quality in terms of moisture content, water absorption index and water solubility index, and had the highest overall acceptance in sensory evaluation. FD well preserved the protein from degradation and formed an ordered porous microstructure. The nitrogen fraction assay revealed that protein was degraded into 40-100kDa fragments during drying in HA, while which was almost not affected by MV and FD. Overall, FD was the most suitable method for drying of meat gel made from hairtail, followed by MV and HA.

Keywords: hairtail, fish protein, vacuum freeze drying, hot air drying, vacuum microwave drying

Running Title: Effect of Drying Methods on Protein of fish meat gel

INTRODUCTION

It is well known that cereal proteins as a single protein resource are generally not complete proteins because of some limited essential amino acids, while fish meat is a good protein resource that could be the compensates. [1] Up to date, Alaska pollock, Pacific whiting, and threadfin bream have been extensively utilized in the processing of fish meat paste, which are considered as nutritionally balanced food and consumed all around the world. [2] The global decrease in high quality fish supply is an initiative to the research of processing and utilization of low value but more abundant fish resources in the current market which typically use low value fish as a major ingredient. [3] For fish meat paste processing, the fish meat is collected after the fish is deboned and gutted. Water soluble proteins, pigment, some enzymes, and fat in the meat are leached out and myofibrillar proteins are predominant in the final product. [4, 5]

The principle of fish meat paste processing is the formation of an elastic gel during the heat processing which help the setting of salt soluble proteins with high water content. [6, 7] This high water content high protein matrix will be enhanced during the cold chain circulation that can avoid the matrix corruption. [8] However, the shelf life of fish meat gel will be significantly reduced if the protein structure is destroyed under an unstable temperature environment. [9-11]

Drying is a commonly used technology to converts liquid and/or wet product into a dry state. Compared with wet materials, the dried counterparts have the benefits of preventing microbial growth and spoilage, ease of handling due to reduction in bulk, and reduced handling costs. [12] Because of the low moisture content and water activity, the dried products are generally more stable under adverse conditions such as fluctuated temperatures. Drying technology is also widely used in traditional aquatic product processing, usually combined with salting and smoking processes. [13]

However, there is lack of information on drying of fish meat gel. Particularly, the effects of drying technologies on the gelling components of fish meat-proteins are not widely investigated. And few reports on hairtail protein property were found, despite that the fish was widely used to produce fish meat gel. The aim of this study was to compare the effect of three drying methods, e.g. hot-air drying, microwave vacuum drying, and vacuum freeze-drying on the protein characteristics of hairtail fish meat gel.

MATERIALS AND METHODS

Materials

Hairtail fish was purchased from a commercial fishing boat in Zhoushan city, China, and was carried to the laboratory in ice within 30 min after its harvest. The fish was manually gutted to collect the fish meat. The meat was bleached with de-ionized water (temperature and time) at 10 ^{o}C for 5 min to remove pigments, fat and water soluble proteins to obtain the fish meat paste.

Preparation of Fish Meat Gel Samples

To prepare the fish gel, NaCl was added to the fish meat paste to a final concentration of 2.5%, and the final moisture was adjusted to 80%. The meat was ground at 4°C for 30 min using a mortar and a pestle to form a fish paste, and then stuffed into stainless steel rings (diameter 3.0 cm) for shaping. [1] As two step heating could result in a better gel strength than one step heating, two step heating was preferred in this study. After incubating at a two-stage heating process of 50°C for 40min followed by 90°C for 20 min, the obtained fish meat gel was cooled down with iced water and was sliced into 1-2cm thickness discs.

Freeze Drying (FD)

The fish gel discs were frozen in a freezer at a temperature of -70°C and then freeze dried in a freeze dryer (Labconco freezon 6Plus, America) operating at -50°C and 1.65Pa for 26 hours. The water content of the samples was in situ monitored with an infrared auto-moisture analyzer (DHS20A, company, China). The freeze dried samples had a water content of 4-5% (w/w). The samples were either analysed immediately or stored in desiccators for further analysis. [14]

Hot Air Drying (HA)

Hot air drying was followed the procedure of Krokida, Karathanos, Maroulis, and Marinos-Kouris. [15] Briefly, fish meat gel discs were placed in metal trays with a sample thickness of 1-2 cm. The samples were dried at 65 °C and air velocity of 1.5m/s for approximately 20 h (V-33 convection cabinet dryer, Despatch Oven Co, Minneapolis, MN).

Microwave Vacuum Drying (MV)

The fish gel discs were dried as described by Therdthai and Northongkom [16], using a microwave vacuum drier (WZD2S, Nanking Sanle, China) consisting of three pairs of magnetrons with a rotating plate. The oven was operated for 40min at a microwave power of 1300 W, pressure of -90 kPa and frequency of 2540 MHz. All experiments were conducted with three independent triplications.

Water Content Determination

The water content of the samples was determined using a vacuum oven (AOAC, 1990). [17]

Water Absorption Index and Water Solubility Index Determination

Water absorption index (WAI) and water solubility index (WSI) were determined according to the method reported by Lee and Rhee with some modification. [14] Briefly, about 0.2g dried samples were immersed in 20 ml of distilled water in 50 ml centrifuge tubes and mixed on a vortex mixer, then the tubes were kept in a water bath at 25°C for 1 h with shaking at regular intervals. The tubes were centrifuged at 3000 rpm for 15 min. The supernatants were separated and their solid contents were determined respectively. The solid sediments were further dried and weighed. The WAI and WSI were calculated by the following equations:

WAI=weight of sediment/weight of dried sediment

WSI (%) = (weight of dissolved solid in supernatant/weight of dry solids)*100

Measurement of whiteness

The whiteness value of the hairtail meat gel was tested by a color difference meter (WSC-S80, Shanghai, China) and calculated according to the following formula: $W=100-[(100-L^*)^2+a^{*2}+b^{*2}]^{1/2}$. [18, 19] Hue-different angle value was calculated by: $h^* = \mathrm{arc\ tg}\ b^*/a^*$. [20]

Protein Degradation determination

The protein concentration was determined by the Biuret method using bovine serum albumin (BSA) as standard. [21] Protein degradation of hairtail meat gels were evaluated by SDS-polyacrylamide gel electrophoresis analysis. The fish meat gel was extracted following the method of Bechtel and Parrish. [22] An aliquot of 20μL extracted sample was subjected to SDS-PAGE electrophoresis under reducing conditions. After electrophoretic running (EPS-300 Tanon vertical electrophoresis apparatus, Shanghai, China), proteins in the gel was stained with Coomassie Brilliant Blue R-250 for further analysis. [23]

Nitrogen Fraction Determination

Aliquots (10 ml) of extracts were mixed with the same volume of 4% trichloroacetic and 10% phosphotungstic acid solutions to obtain non-protein nitrogen (NPN) and 5% phosphotungstic-acid-soluble nitrogen (PTN), respectively. Mixtures were kept at 4°C for 60 min, and the insoluble material was removed by filtration through Whatman no. 4 paper. Total nitrogen, NPN and PTN were determined by the Kjeldahl method. [17] The total nitrogen was considered as total water-soluble nitrogen (WSN) because it was determined in the aqueous phase of the fish meat gel after removal of the insoluble material.

The amino acidic nitrogen (AN) was determined as described by Cambero (1998). [24] The protein nitrogen (PN) was estimated from the difference between WSN and NPN (WSN ± NPN) and the non-protein non-amino-acid nitrogen (NPNAN) was calculated as NPN ± AN. Likewise, the concentrations of peptides with a molecular weight greater than 600 Da (HPPN) were calculated according to the expression HPPN = NPN ± PTN and non-amino-acid nitrogen substances of less than 600 Da (small non-amino-acid nitrogen compounds) were calculated as SNAN = PTN ± AN.

Scanning electron microscopy (SEM)

Microstructures of the hairtail meat gels were determined using a Model XL 30 SEM (Philips, Holland). The gel samples were first fixed with 2.5 % glutaraldehyde in phosphate buffer (pH 7.0) and dehydrated in Hitachi Model HCP-2 critical point dryer with liquid CO_2. After coated with gold-palladium, the microstructures were observed in the SEM and took the scanned image when amplified to 1800 times.

Sensory Evaluation

Overall sensory quality of the fish gel was evaluated on the parameters including color, odor and texture. Samples were assessed by a panel of 6 experienced food sensory evaluation members on the basis of 10-point scale (10-9 excellent, 8-7 good, 6-5 fair and acceptable, 4-3 poor and 2-1 very poor). [25]

Statistical Analysis

The experiments were run in triplicates and the data were presented as mean with standard deviation. Statistical analysis was performed using ORIGIN (version 8.0; Microcal Software Inc., Northampton, MA). The results were analyzed using one-way analysis of variance (ANOVA). Comparison of treatment means was based on Duncan’s multiple range test. Differences were considered significant at the $p < 0.05$ level.

RESULTS AND DISSCUSIONS

Water content, color, WAI and WSI of dried fish meat gel

The water content of the heated fish meat gel was 78-83%, suggesting it is susceptible to microbial contamination and should be maintained in a cold chain environment during circulation. Removing the moisture content through drying could effectively improve the product stability. All the drying conditions of each drying method were accepted as the most popular methods currently used in aquatic food product processing. Under the drying conditions of this experiment, the FD, HA and MV methods had reduced the water content of the fish meat gel to 4.0, 11.8 and 8.1%, respectively (Table 1). The hue-different angle value of FD and MV was within the range of 80-90, suggesting the color change from green to yellow was negligible. [26] But the HA sample had the lowest whiteness among all the tested samples. Possibly, the longest heating process of HA was beneficial to the Maillard reaction which generated more black/brown compounds and consequently decreased the whiteness value. [27]

Hot air drying (HA) was a convective drying process employing heated air as the heat and humidity carrier. Drying conditions such as temperature, velocity, relative humidity, as well as various contamination sources could be well controlled. Compared with naturally drying method (e.g. sun drying) HA result in better quality products. [28] Another advantage of this method is that it is easy to implement because of its low investment costs and simple operation. Therefore, hot air drying has been widely used to dry aquatic products as well. [29] In this study, fish meat gel was dried at 65°C for approximately 20 h. The obtained sample had a water content of 11.8%, which could be applied in food drying processing, though much higher than that of FD and MV.

In recent years, microwave drying has gained popularity as an alternative drying method in the food industry, owing to its ability to rapidly heat dielectric materials through volumetric dissipation of microwave energy. [30] On the other hand, microwave drying is also effective in color preservation. [31] In this study, water content was much lower in the MV sample, being 8.1%, with the whiteness (84.0) close to the fish meat gel (89.9) before drying, although significant difference was still detected.

FD is one of the best method of water removal for most of the foods because the primary flavor, color, structure, and the nutrient compositions are maintained to a great extent and final products have better rehydration capacity than those produced using other drying methods. [32] In this study, FD samples had the best whiteness of 88.4 and the lowest water content of 4.0%.

Water absorption index (WAI) and water solubility index (WSI) of a dried material depend on several factors such as original nutrition components, enzyme content and thermal history. [33, 34] It was observed that the WAI and WSI of fish meat gel were dependent on the drying methods (Table 1). FD as well as MV products showed higher WAI and WSI values, while HA product had the lowest, suggesting FD and MV meat gels have better consuming characteristics.

Sensory Evaluation

For all food resources, sensory evaluation on appearance, odor, taste and texture is very important as it reflects direct potential consumer preference. [35] In this study, FD fish meat gel obtained the highest overall acceptation for sensory score, followed by MV. The FD fish meat gel was crisp with a pleasant fresh fishy smell. The overall appearance of FD sample was almost the same as the heated fish meat gel, suggesting FD had preserved the shape very well. Samples dried by HA had the lowest score of overall acceptance because of its bad appearance and texture. Appearance, especially the whiteness reflects the color of the fish meat, is one of the most important attributes in the food industry, affecting the acceptability by consumers. The surface of HA samples collapsed into a curve with a brown color. The HA samples were also hard during chewing, resulting in lower texture and taste scores.

Nitrogen Fraction Determination

Effect of drying methods on the release of nitrogen compounds from the fish meat gel was studied. The ratios of TCA-SN, WSN and PTA-SN/WSN could reveal the degradation depth of proteins. [36] Table 3 shows the concentrations (g/100 ml) of water-soluble nitrogen (WSN), protein nitrogen (PN), nitrogen in peptides of molecular weight greater than 600 Da (HPPN), nitrogen in non-amino-acid substances smaller than 600 Da (SNAN) and amino acid nitrogen (AN) of fish meat gel after different drying method. The nitrogen was mainly present in peptides of less than 600 Da with the ratio about 50% of the WSN, followed by amino acidic fraction (AN). FD drying had the highest protein nitrogen content, which showed a better protein nitrogen preserving capacity than that of HA and MV. High protein nitrogen content might contribute to flavor or indirectly contribute as flavor precursors of the fish products. [37]

Protein Degradation Assay

The fish meat was mainly composed of myriad myofibrils, which contained two predominant proteins of myosin and actin. Myosin comprises approximately 55-60% of the total myofibrillar proteins. Each myosin molecule is composed of two 220KDa heavy amino acid chains and two pairs of light chains. The myosin heavy chains (MHC) could be released and revealed in the SDS-PAGE profile. Actin (AC) comprised 15-30% of the myofibrillar protein. [38] In this study, heated fish meat gel without drying process was used as control. The protein profile of control was almost the same as that of the unheated fish meat paste. After drying, actin was remained almost intact by either FD, HA or MV method, suggesting no degradation was occurred (Fig. 1). In case of MHC, the density of MHC band of FD and MV samples did not changed. However, the band of MHC in HA sample was obviously narrowed and new bands between MHC and AC were generated, suggesting that MHC was degraded during the HA drying process. The endogenous proteinase in the heated gel might still active and degraded the MHC during HA drying. It was reported that some proteinase is heat insensitive, for example, the optimum temperature of cathepsin L, one of the gel dis-integration involved proteinases, was reported to be about 50-60°C. [39] The HA drying was undertaken at 65°C for 20h. The longtime heating at this temperature might have caused severe protein degradation. The results of nitrogen fraction assay revealed that most of the protein of HA sample degraded into peptides with molecular above 600Da. By SDS-PAGE assay, the peptides should be within the range of 200-40KDa, also suggesting the protein degradation during HA drying.

Microstructures of the dried fish meat gels from different drying methods

Although hot air drying has the advantages of low investment costs and simple operation, it generally involves high energy consumption and long drying times. The size of the food material and the drying temperature significantly affect all quality attributes of the dried products. It was reported that an air temperature above 100°C was positive to the quality of shrimp, with high percentage of rehydration, low maximum shear force and high value of redness. [40, 41] However, Kowalski and Pawłowski observed that although higher drying temperature (100 °C) resulted in a higher drying rate and reduced drying time, the quality of the dried product was worse than that dried at a lower temperature (65°C). [42] In the present study, the HA fish meat gel was dried at 65°C. As shown in figure 2b, the HA dried matrix collapsed entirely from the surface to the center to form a very tight compact structure. This tight microstructure may have contributed to the low WAI and WSI values (table 1) as mentioned above, and also negatively affect the overall acceptance during the sensory evaluation (Table 2).

Although microwave drying is getting more and more acceptance in both industry and home applications, the texture of the products might be damaged due to the rapid mass transfer during the drying process. In addition, non-uniformity of electromagnetic field could create hot spots during microwave drying and result in burn points on the product surface. [43, 44] In this study, large spots and holes were observed on the surface and inside of the MV samples (Figure 2 f). Under vacuum condition, the water is transferred in a rapid way from the inside of the sample and evaporated from the surface, which could cause a number of burning spots inside the matrix in a very short time. [45] A collapsed surface was formed because it could not stand the high speed evaporation in such high water content (80%) from both inside and the surface of the sample in a very short drying time (40 min) (Figure 2 e). Because of the spotted structures inside, the MV sample had better WSI, WAI and overall acceptance than the HA sample as described above.

FD under vacuum conditions was first developed for protein pharmaceutical manufacturing. [46] Currently, it was applied in drying of heat sensitive food and other biological materials. It was considered to be one of the best water removal method for most kinds of foods because the primary flavor, color, structure, and the nutrient compositions can be maintained to a great extent and final products have a better rehydration capacity than those produced using other drying methods. [29] As described above, the FD sample had the highest sensory scores, best WSI, WAI and highest protein nitrogen fraction. The myofibrillar proteins were well preserved after vacuum freeze drying. The SEM micrographs revealed that the FD generated bigger size pores of homogeneity and a more ordered structure (Fig. 2), which was consist with the reports of other food matrix. [47, 48] An amplified microscopy by 5000 times clearly showed that the wall of pores was homogenously arranged, assuring the FD dried samples recover water when put into water again. This could be one of the factors that attributed to the best quality of the fish meat protein gel by FD.

Different from other matrix, such as rice, [49, 50] fruits [51] and maize, [52] etc., drying matrix of protein showed to be quite sensitive to the vacuum. Under common pressure, although in low temperature of HA at 65°C, the protein in hairtail fish meat was degraded and a collapsed microstructure was formed (Fig. 2, b). Under vacuum condition, in case of MV and FD, the less degradation of protein and an ordered microstructure was observed. This might partly be due to prevent of oxidation from the protein matrix by the vacuum condition. Further studies need be undertaken yet.

CONCLUSIONS

The effects of 3 different drying methods, including hot air drying (HA), microwave vacuum drying (MV) and freeze drying (FD), were investigated on the drying of hairtail fish meat gel. The FD method could effectively preserve the protein from degradation during the drying process and obtained the best sensory scores for appearance, odor, texture and overall acceptance. The FD sample also had the highest WAI, WSI and protein nitrogen fraction. SEM results revealed that FD could preserve the fish meat gel microstructure by forming homogenous ordered structure. Compared with HA, MV showed advantages in preservation of protein with a porous structure inside, although not so effective to that of FD. For drying of the high protein and high moisture contents fish meat gel, FD was recommended as the most suitable method.

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REFFERENCES

1. Soottawat, B.; Wonnop, V.; Siriporn, R.; Shoichiro, I.; Munihiko, T. Gel forming properties of surimi produced from bigeye snapper, Priacanthus tayenus and P macracanthus, stored in ice. Journal of Science of Food and Agriculture **2002**, 82(13), 1442–1451.

2. Yongsawatdigul, J.; Worratao, A.; Park, J. Effect of endogeneous transglutaminase on threadfin bream surimi gelation. Journal of Food Science **2002**, 67 (9), 3258–3263.

3. Esturk, O.; Park, J.; Thawornchinsombut, S. Thermal sensitivity of fish proteins from various species on rheological properties of gel. Journal of Food Science **2004**, 69 (7), 412–416.

4. Vilhelmsson, O. The state of enzyme biotechnology in the fish processing industry. Trends in Food Science and Technology **1997**, 8(8), 266–270.

5. Carvajal, P.A.; Lanier, T.C.; MacDonald, G.A. Stabilization of proteins in surimi. In Surimi and surimi seafood; Park J.W., Eds; Taylor & Francis Group; **2005**; 163–225.

6. Aguilera, J.M.; Rademacher, B. Protein gels. In Proteins in food processing; Yada, R.Y. Eds; Cambridge, U.K.; Woodhead Publishing Ltd; **2004**; 468 – 482.

7. Lanier, T.C.; Carvajal, P.A.; Yongsawatdigul, J. Surimi gelation chemistry. In: Surimi and surimi seafood. Park J.W., Eds; Taylor & Francis Group; **2005**; 435 – 489.

8. An, H.J.; Peters, M.Y.; Seymour, T.A. Roles of endogenous enzymes in surimi gelation. Trends in Food Science and Technology **1996**, 7(10), 321 – 327.

9. Kurokawa, T. Kamaboko-forming ability of frozen and ice stored lizard fish. Bulleting of the Japanese Society of Scientific Fisheries **1979**, 45, 1551-1555.

10. Lian, P.; Lee, C. M.; Hufnagel, L. Physicochemical properties of frozen Red Hake mince as affected by cryoproteetive ingredients. Journal of Food Science **2000**, 65(7), 1117-1120.

11. Pornrat, S.; Sumate, T.; Rommanee, S. Changes in the uhrastructure and texture of prawn muscle (Macrobrachuim rosenbergii) during cold storage Journal of Food Science and Technology **2007**, 40, 1747-1754.

12. Dev, Satyanarayan R. S.; Raghavan, Vijaya G. S. Advancements in drying techniques for food, fiber, and fuel. Drying Technology **2012**, 30(11-12), 1147-1159.

13. Bellagha, S.; Sahli, A.; Farhat, A.; Kechaou, N.; Glenza, A. Studies on salting and drying of sardine (*Sardinella aurita*):Experimental kinetics and modeling. Journal of Food Engineering **2007**, 78, 947–952.

14. Lee, S.; Rhee, C. Effect of heating condition and starch concentration on the structure and properties of freeze-dried rice starch paste. Food Research International **2007**, 40, 215-223.

15. K. Krokida, M.; Karathanos, V.; Maroulis, Z.; Marinos-Kouris, D. Drying kinetics of some vegetables. Journal of Food Engineering **2003**, 59 (4), 391 − 403.

16. Therdthai, N.*;* Northongkom, H. Characterization of hot air drying and microwave vacuum drying of fingerroot (*Boesenbergia pandurata*). International Journal of Food Science and Technology **2011**, 46, 601–607.

17. Association of Official Analytical Chemists (AOAC) Official Methods of Analysis, Washington DC, **1990**.

18. Young, K.; Whittle, K. Colour measurement of fish minces using Hunter L, a, b values. Journal of the Science of Food and Agriculture **1985**, 36:383.

19. Juan, C.; Morrissey, M. Effect of high pressure processing (HPP) on shelf life of albacore tuna minced muscle. Innovative Food and Emerging Technologies **2006**, 7:19-27.

20. Tolvaj, L.; Mitsui, K. Correlation between hue angle and lightness of light irradiated wood. Polymer Degradation and Stability **2010**, 95(4), 638–642.

21. Robinson, H; Hodgen, C. The biuret reaction in the determination of serum protein. I. A study of the condition necessary for the production of the stable color which bears a quantitative relationship to the protein concentration. Journal of Biological Chemistry **1940**, 135, 707-725.

22. Bechtel, P.; Parrish, J. Effects of postmortem storage and temperature on muscle protein degradation: Analysis by SDS gel electrophoresis. Journal of Food Science **1983**, 48, 294.

23. Laemmli, U. K. Cleavage and structural proteins during assembly of bacteriophage T4. Nature **1970**, 227, 680–685.

24. Cambero, M.I.; Jaramillo, C.J.; Ordoñez, J.A.; Cobos, A.; Pereira-Lima, C.I.; García De Fernando, G.D. Effect of cooking conditions on the flavour compounds and composition of shrimp (*Parapenaeus longirostris)* broth. Zeitschrift fur Lebensmittel -Untersuchung und -Forschung **1998**, 206(5), 311-322.

25. Kreuzer, R. Cephalopods: Handling, processing and products. FAO Fisheries Technical Paper Nr 254, **1984**, 154.

26. Tian; M.; B. Woolf, A.; Bowen, J.; Ferguson, I. Changes in Color and Chlorophyll Fluorescence of Broccoli Florets following Hot Water Treatment. Journal of the American Society for HorticulturalScience **1996**, 121(2), 310-313.

27. Jaeger, H.; Janositz, A.; Knorr, D. The Maillard reaction and its control during food processing. Pathologie Biologie **2010**, 58(3), 207–213.

28. Zhang, G.C.; Mao, Zh. Research advances of aquatic product drying technologies. Transactions of the CSAE **2004**, 20, 297－300.

29. Wang, Y.; Zhang, M.; Mujumdar, A. S. Trends in Processing Technologies for Dried Aquatic Products, Drying Technology **2011**, 29(4), 382-394.

30. Cui, Z.; Li, C.; Song, C.; Song, Y. Combined microwave-vacuum and freeze drying of carrot and apple chips. Drying Technology **2008**, 26, 1517–1523.

31. Therdthai, N.; Zhou, W. Characterization of microwave vacuum drying and hot air drying of mint leaves (*Mentha cordifolia* Opiz ex Fresen). Journal of Food Engineering **2009**, 91, 482–489.

32. Rahman, M.S. Drying of fish and seafood. In Handbook of Industrial Drying, 3rd ed.; Mujumdar, A.S., Ed.; CRC Press: Boca Raton, FL, **2006**; 552－554.

33. Minoru, J.; Hashimoto, M; Victoria, M; Grossmann, E. Effects of extrusion conditions on quality of cassava bran/cassava starch extrudates. International Journal of Food Science and Technology **2003**, 38(5),511–517.

34. González-Sotoa, R.A.; Mora-Escobedob, R.; Hernández-Sánchezb, H.; Sánchez-Riveraa, M.; Bello-Péreza,, L.A. The influence of time and storage temperature on resistant starch formation from autoclaved debranched banana starch. Food Research International **2007**, 40(2), 304–310.

35. Claudia, R.; Moral, A. Sensory and biochemical aspects of quality of whole big-eye tuna during bulk storage in controlled atmospheres. Food Chemistry **2005**, 89, 347–354.

36. Chun, C.; Zhao, M..; Zhang, X.; Yang, J. Protein degradation of extensive enzymatic hydrolysis of decapterus maruadsi. Transactions of the CSAE **2006**, 22(1), 147-152.

37. Toldrá, F.; Flores, M.; Sanz, Y. Dry-cured ham flavour: Enzymatic generation and process influence. Food Chemistry **1997**, 59(4), 523-530.

38. Soottawat, B.; Wonnop, V. Transglutaminase-mediated setting in big-eye snapper surimi. Food Research International **2003**, 36, 253–266.

39. Hu, Y.; Morioka, K.; Itoh, Y. Hydrolysis of Surimi Paste from Walleye Pollock by the Cysteine

Proteinase Cathepsin L and the Effect of the Proteinase Inhibitor (E-64) on Gelation. Food Chemistry **2007,** 104(2), 702-708.

40. Tapaneyasin, R.; Devahastin, S.; Tansakul, A. Drying methods and quality of shrimp dried in a jet-spouted bed dryer. Journal of Food Process Engineering **2005**, 28, 35－52.

41. Prachayawarakorn, S.; Soponronnarit, S.; Wetchacama, S.; Jaisut,D. Desorption isotherms and drying characteristics of shrimp in superheated steam and hot air. Drying Technology **2002**, 20, 669–684.

42. Kowalski, S.J.; Pawłowski, A. Drying of wet materials in intermittent conditions. Drying Technology **2010**, 28(5), 636－643.

43. Therdthai, N.*;* Zhou, W. Characterization of microwave vacuum drying and hot air drying of mint leaves. Journal of Food Engineering **2009**, 91, 482–489.

44. Durance, T.T.*;* Wang, J.H. Energy consumption, density, and rehydration rate of vacuum microwave and hot-air convection-dehydrated tomatoes. Journal of Food Science **2002**, 67, 2212–2216.

45. Zhang, J.*;* Zang, M.*;* Shan, L.*;* Fang, Z. Microwave-vacuum heating parameters for processing savory crisp bighead carp (*Hypophthalmichthys nobilis*) slice. Journal of Food Engineering **2007**, 79, 885–891.

46. Jeff, J.; Schwegman, L.; Hardwick, M.; and Michael, J. Practical Formulation and Process Development of Freeze-Dried Products.Pharmaceutical Development and Technology **2005**, 10(2), 151-173.

47. Adela, M.; Gloria, I.; Orregob, C. Effect of freezing rate on quality parameters of freeze dried soursop fruit pulp. Journal of Food Engineering **2012**, 111(2), 360–365.

48. Taisuke, U.; Akio, T. Effect of Dehydration Method on the Physical Properties of Fresh-cut Radish after Freezing and after Post-thaw Rehydration in the Dehydro-freezing Technique. Journal of the Japanese society for food science and technology **2012**, 59(3), 115-121.

49. Srisang, N.; Prachayawarakorn, S.; Varanyanond, W.; Soponronnarit, S. Germinated brown rice drying by hot-air fluidization technique. Drying Technology **2009**, 29, 55-63.

50. Adhikari, B.; Chaudhary, D.S.; Clerfeuille, E. Effect of plasticizers on the moisture migration behavior of low-amylose starch films during drying. Drying Technology **2010**, 28, 468－480.

51. Mayor, L.; Silva, M.A.; Sereno, A.M. Microstructural changes during drying of apple slices. Drying Technology **2005**, 23, 2261-2276.

52. Meshram, M.W.; Patil, V.V.; Waje, S.S.; Thorat, B.N. Simultaneous gelatinization and drying of maize starch in a single-screw extruder. Drying Technology **2009**, 27, 113-122.

Captions of Figures

FIG.1. SDS-PAGE profile of proteins of fish meat gel from different drying methods

M: marker; 1: unheated fish meat paste; 2: control (heated fish meat gel); 3: FD sample (heated fish meat gel dried by FD); 4: HA sample (heated fish meat gel dried by HA); 5: MV sample (heated fish meat gel dried by MV)

FIG.2. Micro-structure of fish meat gel obtained by different drying methods

a: unheated fish meat paste (×1800); b: HA sample (heated fish meat gel dried by HA, ×1800); c: FD sample (heated fish meat gel dried by FD, ×1800); d: FD sample (heated fish meat gel dried by FD, ×5000); e: Inside of MV sample (heated fish meat gel dried by MV, ×1800); f: Surface of MV sample (heated fish meat gel dried by MV, ×1800)

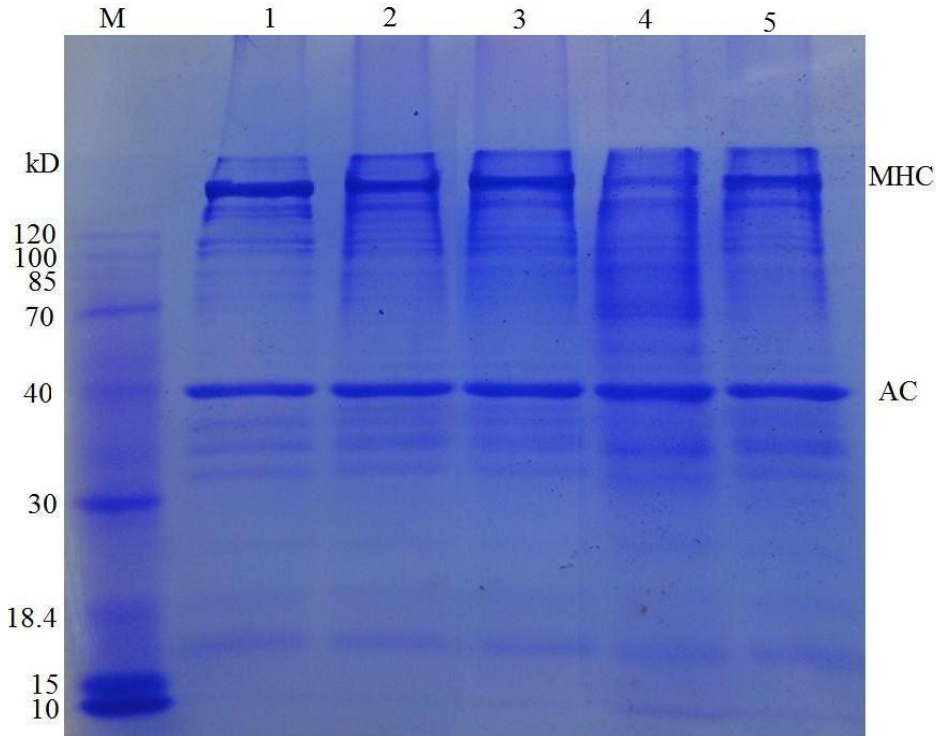
Captions of Tables

TABLE 1 Water content, color, WAI and WSI of hairtail fish meat gel dried from different methods

TABLE 2 Sensory evaluation of hairtail fish meat obtained by different drying methods

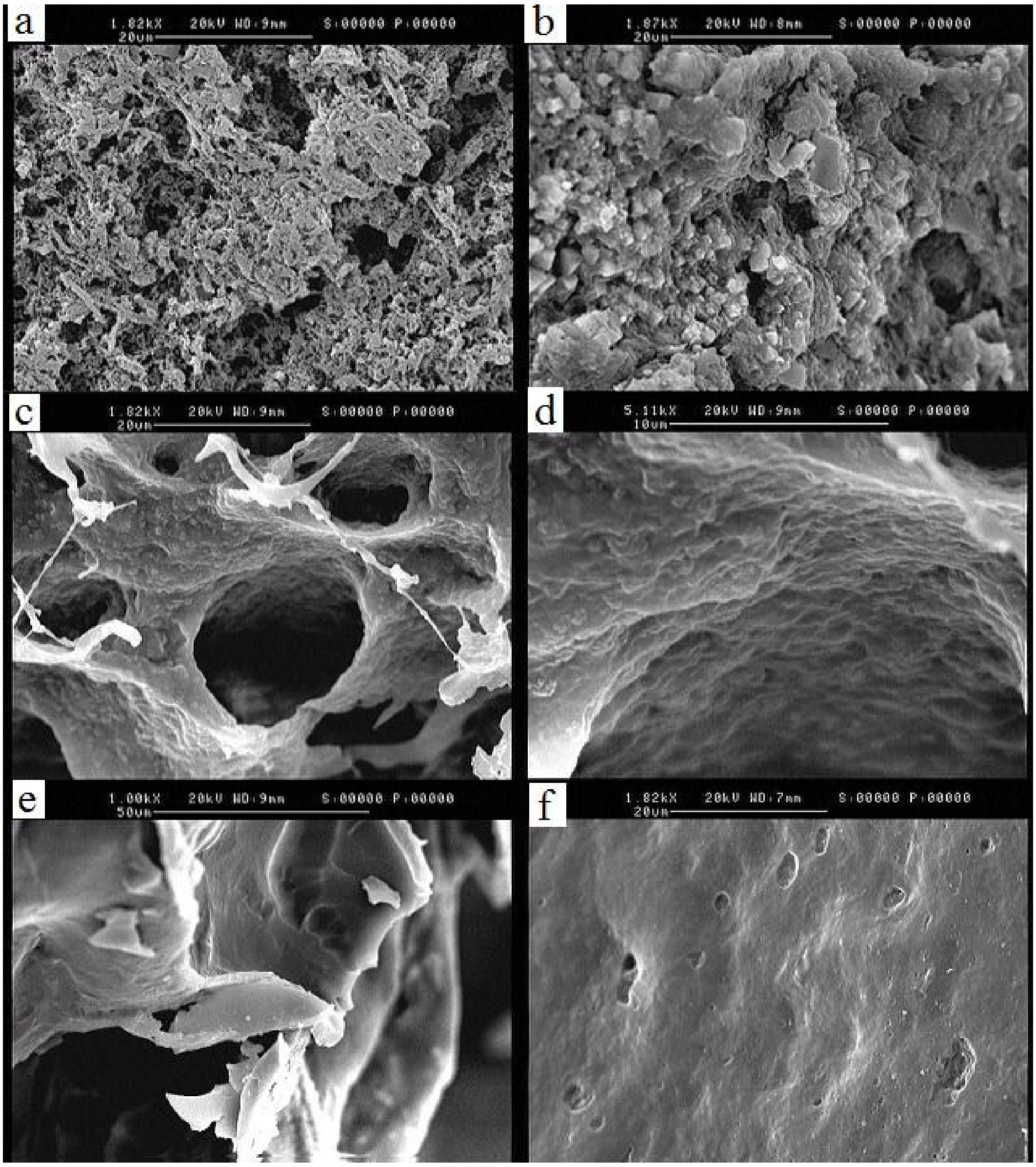
TABLE 3 Concentration of nitrogen fractions in the dried samples

FIG. 1.



M: marker; 1: unheated fish meat paste; 2: control (heated fish meat gel); 3: FD sample (heated fish meat gel dried by FD); 4: HA sample (heated fish meat gel dried by HA); 5: MV sample (heated fish meat gel dried by MV)

FIG. 2.



a: unheated fish meat paste (×1800); b: HA sample (heated fish meat gel dried by HA, ×1800); c: FD sample (heated fish meat gel dried by FD, ×1800); d: FD sample (heated fish meat gel dried by FD, ×5000); e: Inside of MV sample (heated fish meat gel dried by MV, ×1800); f: Surface of MV sample (heated fish meat gel dried by MV, ×1800)

TABLE 1

Water content, color, WAI and WSI of hairtail fish meat gel dried fromdifferent methods

Drying Methods	Wh	θ (^{o})	Water content (%)	WAI	WSI (%)
Control	89.9±1.5[a]	88.9±0.8[a]	80.5±1.2[a]	-	-
FD	89.4±1.8[a]	88.4±0.9[a]	4.0±0.6[a]	5.0±0.8[a]	18.5±0.9[a]
HA	76.4±1.2[b]	78.8±0.8[a]	11.8±0.9[b]	2.2±0.7[b]	12.4±0.8[b]
MW	84.0±1.9[c]	88.9±0.7[a]	8.1±0.8[c]	5.4±0.8[a]	16.7±0.6[c]

[a-c] Different letters in the same column are significantly different ($p<0.05$).

TABLE 2

Sensory evaluation of hairtail fish meat obtained by different drying methods

Drying Methods	Appearance	Odor	Taste	Texture	Overall acceptability
FD	9.8±0.8[a]	8.9±0.5[a]	9.4±0.5[a]	9.2±0.6[a]	9.5±0.5[a]
HA	6.4±0.7[b]	6.8±0.4[b]	5.8±0.3[b]	4.8±0.2[b]	6.4±0.5[b]
MW	7.8±0.6[c]	7.7±0.6[c]	6.9±0.4[c]	5.8±0.5[c]	7.2±0.4[c]

[a-c] Means with different superscripts in the same column are significantly different ($p<0.05$).

TABLE 3

Concentration of nitrogen fractions in the dried samples

Drying Methods	WSN	PN	HPPN	SNAN	AN
Control	0.85 ± 0.5^{a}	0.05 ± 0.8^{a}	0.04 ± 0.8^{a}	0.48 ± 1.8^{a}	0.29 ± 1.1^{a}
FD	0.87 ± 0.8^{a}	0.07 ± 0.9^{b}	0.04 ± 0.6^{a}	0.48 ± 1.6^{a}	0.27 ± 0.9^{a}
HA	0.86 ± 0.9^{a}	0.02 ± 0.8^{c}	0.07 ± 0.9^{b}	0.40 ± 1.7^{b}	0.33 ± 1.4^{b}
MW	0.84 ± 0.9^{a}	0.05 ± 0.7^{a}	0.03 ± 0.8^{c}	0.43 ± 1.5^{c}	0.30 ± 1.6^{a}

[a-c] Means with different superscripts in the same column are significantly different ($p<0.05$).