CARPATHIAN JOURNAL OF FOOD SCIENCE AND TECHNOLOGY

journal homepage: http://chimie-biologie.ubm.ro/carpathian_journal/index.html

STUDY OF FREEZE-THAWING ON THE PROCESS OF TILAPIA FILLETS HEAT PUMP DRYING

Min Li*, Zhi-qiang Guan, Bao-chuan Wu, Yang-yang Wu

College of Engineering, Guangdong Ocean University, Zhanjiang, 524088, Guangdong, China
**lim@gdou.edu.cn*

Article history:
Received:
4 January 2016
Accepted in revised form:
22 February 2016

Keywords:
Tilapia fillets
Heat pump drying
Freeze-thawing
Drying time
Drying rate

ABSTRACT

In order to investigate the effects of freeze-thaw pretreatment on drying time of tilapia fillets by heat pump drying. The effects of freezing temperature (-10, -20, -30, -40 and -50ºC), freezing time (0.5, 1, 1.5, 2 and 2.5 h), thawing temperature (5, 10, 15, 20 and 25ºC) and melting time (1, 1.5, 2, 2.5 and 3h) on heat pump drying time of tilapia fillets and the drying speed of dried tilapia fillets were investigated in this paper. Furthermore, the heat pump drying speed curve of tilapia fillets had been gained under different freeze-thaw conditions, and results indicated that: drying time and drying speed were improved under moderate freeze-thaw condition. Along with the increase of freezing temperature, freezing time, melting temperature and melting time, drying time decreased firstly and then increased with a nadir. So, while under the same conditions, if the frozen temperature was between -20ºC and -30ºC, the melting temperature was 20ºC and the freezing time was restricted by an hour, then the drying time was shortened and the drying speed was accelerated. Moderate freeze-thaw condition can reduce the drying time of tilapia fillets and accelerate the drying speed by heat pump drying and a reference for the low temperature heat pump drying pretreatment technology to update similar aquatic products.

1. Introduction

Tilapia is one of the aquatic products with high moisture and protein content, as a result of which, fresh fish is very susceptible to spoilage, so drying dehydration is a quite common way for storage (Sismotto et al., 2014; Cheng, 2015; Kituu, 2010). Undoubtedly, hot air drying (Xiao et al., 2010) is the most common tilapia drying process, but the quality of dried products is greatly affected by the drying time and drying temperature, therefore, it is difficult to control appropriate drying conditions to improve the quality of the drying tilapia fillets and shorten the drying time simultaneously (Zhen-hua et al., 2011). Additionally, the simply low temperature heat pump drying (Goh et al., 2011) can not avoid the action of microorganisms resulting in quality mutation of the products because of a longer drying time. However, adding pretreatment reagents is favorable to shortening the drying time, and improving the performance of dry goods (Zheng et al., 2013). But adding the pure chemical pretreatment reagent is limited by the volume index of national standard. Freeze-thawing as a method of drying process in the physical pretreatment have also been used in the drying process of other fields (Yucheng, 2009), and as a preliminary study has been pretreated before drying fruits and vegetables. And it is said that it is easy for food biological tissue or reactive porous media to receive dehydration after freeze-thawing treatment (Ting et al., 2013). For now, freeze-thawing treatment research is mostly concentrated in the freeze-thawing damage to the organization on aquatic products and other meat products (Ramírez et al., 2011). Previous studies had shown that dried and cold swap could promote drying process. Overall, tilapia fillets would be used as a raw material in this paper, and this experiment tried to match freeze- thawing conditions better , in order to apply the freeze -thawing method to the tilapia fillets dry pretreatment process , which could strengthen the advantage of freeze-thawing that it benefits the dehydration and drying, while weakening its disadvantage of mutating the organizational structure. So the aim was to explore a new method of drying pretreatment which would provide the basis for the development of dehydration pretreatment process of aquatic products and other meat products.

2. Materials and methods

2.1. Raw materials and Sample preparation

Materials: fresh tilapia, purchased from Zhanjiang Gongnong market, weighing about 1.5 kg/bar.

Sample preparation: The average initial moisture content of the tilapia fillet samples was 5 kg/kg expressed in dry basis (d.b.) or 80% in wet basis. A commercially available fresh tilapia was killed quickly, the meats slices were taken after removing scales, head and tail, innards. And then it was required to control the standard of the fish fillet is 100 mm × 50 mm × 5 mm each (weight was about 30g). After that, external water of fillets was fully absorbed by absorbent paper after cleaning, before being weighed standby.

2.2. Main Instruments and Equipment

Self-built heat pump drying device (Guan et al., 2013): 3P power, temperature -20-80^{o}C, humidity 20% - 80%; HHS-type electric heated water bath (Shanghai Industrial Co., Ltd. Boxun medical equipment factory);DZF-6050 vacuum oven (Shanghai Jing Hong Laboratory Instrument Co., Ltd.); BD-730LT-86L-I ultra-low temperature freezer (Qingdao Haier Group); FYL-YS-50L incubator (Beijing Fuyi Electric Co.); T-18 homogenizer (Germany IKA group); GL-10LMD refrigerated centrifuge (Hunan Xingke Scientific Instrument Co., Ltd.); Sigma 1-14 high-speed desktop centrifuge (Germany Sigmal Company); AY120 analytical balance (Shimadzu Corporation); Drying temperature and air velocity data were collected by multi-channel digital instrument XSD (XSD/A-H3IIIS2, Automation Equipment Co., Ltd., Guangzhou Kunlun). The temperature was measured by Duwei ATH402 plastic pipe temperature and humidity transmitter (Hefei Dewey Instrument Co., Ltd. production). The hot air velocity was measured by Deweida EE65 air velocity transmitter (Shenzhen Deweida Instrument Co., Ltd. Production).

2.3. Methods

2.3.1. Process flow

Raw fish—section—weighing—freezing—thawing—weighing—heat pump drying—determining index

2.3.2. Points in operation

Fish fillets freezing and thawing: according to the experimental conditions, the cryostat's and the incubator's temperature were set to a predetermined value, and the fish fillets will be loaded into the polyethylene bags sent to the cryostat later for being frozen for a period of time. Afterwards, the fish fillets would be moved into the incubator for thawing for a period of time.

Heat pump drying: For tilapia fillets with 5 mm thickness, because there would be a better drying quality under 45^{o}C as the heat pump temperature, 2.5 m/s as wind speed and 30% humidity conditions around, heat pump drying tested the tilapia fillets under this circumstance (Li Min et al., 2011). Firstly, the parameters of heat pump drying device were required to be adjusted to predetermined value of the test requirements. Secondly, after removing the frozen-thawed fish fillets from polyethylene plastic bags, absorbent paper gently and repeatedly suck the seeping water on the surface and fillet weight would be measured accordingly .Finally, move the fish fillets into the clean barbed wire tray of heat pump oven afterwards. Then, the fish fillets would receive drying treatment.

2.3.3. Experimental procedure

With the heat pump drying conditions and fish size unchanged, drying pretreatment experiments were performed at different freezing temperatures (-10, -20, -30, -40 and -50°C), at different freezing time (0.5, 1.0, 1.5, 2.0 and 2.5h), at different thawing temperatures (5, 10, 15, 20 and 25°C) and at different thawing time (1.0, 1.5, 2.0, 2.5 and 3.0h) pretreatment, weighting, then added in the heat pump dryer. The weight of the sample was measured at one hour intervals. For every batch of dried sample, the moisture content was determined, the drying procedure was not stopped until the moisture content of dry basis reached 0.30±0.02 g/g. Moreover, the experimental group without freeze-thawing pretreatment worked as the contrast group. Each run in the experiment was done in triplicate.

2.4. Indicators and Evaluation Methods

The moisture content of the test sample was determined according to the vacuum oven method (AOAC, 2005). At regular time intervals during the drying period, samples were taken out and dried in a dryer at 105°C for drying to constant weight and weighed (DZF-6050, Shanghai Experiment Instrument Co. Ltd., China).

Calculation of moisture ratio (W)

W represents the moisture ratio of dry basis and can be expressed as follows:

$$W = \frac{m_t - m_1}{m_1} \tag{1}$$

where m_t is the moisture content of the product at each moment, m1 is the samples dry weight.

Determination of drying rate curves

The drying rate represents the average changes of dry basis moisture content in per unit time. In order to reflect the rate of drying, the drying rate curves were plotted. The average drying rate was calculated by the formula as follows:

$$v = (w_2 - w_1)/(t_2 - t_1) \tag{2}$$

where, v is the rate of drying; w_1, w_2, respectively, represent the moisture content on a dry basis (g/g) in t_1 and t_2; t_1, t_2 are the drying time (h).

2.5. Statistical Analysis

All the tests were done in triplicate and data were averaged. Standard deviation was also calculated. Analysis of variance was used to evaluate significant differences (P<0.05) between the means for each sample.

3. Results and discussions

3.1. Drying curve and drying rate curve of different freezing time

Fixed melting time was 2.0 h, freezing temperature was at -40°C and melting temperature was at 25°C and under this condition, freezing-thawing pretreatments of fish fillets were using different freeze time: 0.5h, 1.0h, 1.5h, 2.0h and 2.5h respectively, to investigate the effects of different freezing time on the drying time and drying rate of fish fillets heat pump drying. The results are shown in Figure 1.

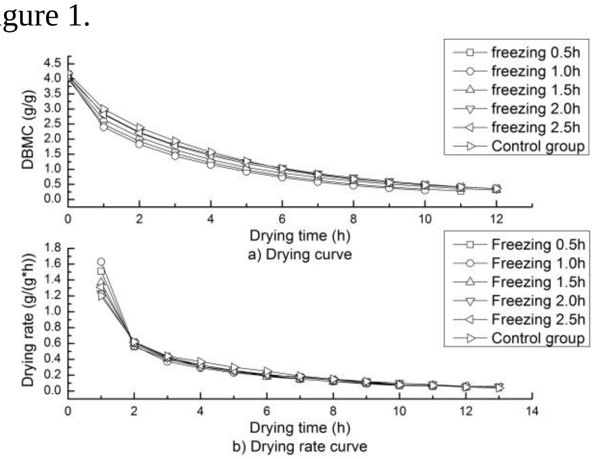

Figure 1. Effect of different freezing time of freeze-thaw pretreatment on drying time and drying rate (DBMC- Dry Basis Moisture Content, The same below)

As can be seen in Figure 1(a), different freezing time of freeze-thawing pre-processing can generate obvious effects on the drying time of fish fillets which dried with the same moisture content finally. Along with the increase in freezing time, results showed that the drying time of slices firstly decreased and then increased. When freezing time was less than 2.0h, the drying time of experimental group was less than that of contrast group without pretreatment, and surprisingly, there was a minimum drying time which was 10 hours experiencing the freezing time of 1.0h, which was significantly shorter than the drying time of 13h of the untreated control group. However, when the freezing time was more than 1.5h, with further increase in freezing time, the gap of drying time between the control group and the others was getting smaller and smaller. So, it showed the best freezing time was 1.0h by this test. Under a certain freezing temperature condition, along with the increase in freezing time, ice crystals would be formed layer by layer and get inward penetration constantly, which might cause a certain degree of damage to the muscle tissue, and the time period of 1 hours could just freeze the fillets thoroughly, and this freezing time might match the thawing conditions well. Furthermore, the fish fillets might not be frozen sufficiently when the freezing time was less than 1h, so that the permeability and detachment of internal moisture was not sufficient, which made the improvement of the drying time not obvious. If the freezing time was more than one hour, with prolonged freezing time, the condition would result in excessive frozen fillets, and increase the compacting properties of ice crystals, the competition pattern of the ice crystal interface had changed, and reduce the moisture from the proteins or other polymer compound, therefore, it could not reach to the maximum extent of tissue damage in the limited melting time, which may be the cause of the above phenomena.

As can be seen from the drying rate curve in Figure 1(b), for the samples of the freeze-thawing pretreatment of different freezing time, there was a great difference among the drying rate of the first 1h, the drying rate after 1h freezing time had the maximum, while the drying rate after 2h freezing time was the minimum. But both of them were higher than the control group. Therefore, freeze-thawing pretreatment promoted the water escape of the drying section so that the water loss rate of initial drying period greatly increased. When to the drying time was 2h, the drying speed was substantially parallel.

3.2. Drying curve and drying rate curve of different melting time

Fixed freezing time was 1.5h, freezing temperature was -40^{o}C and melting temperature was 25^{o}C, and under this condition, freeze-thawing pretreatment of fish fillets were carried out in different melting time: 1.0h, 1.5h, 2.0h, 2.5h and 3.0h respectively, to investigate the effects of different melting time on the drying time of fish fillets, the results were shown in Figure 2.

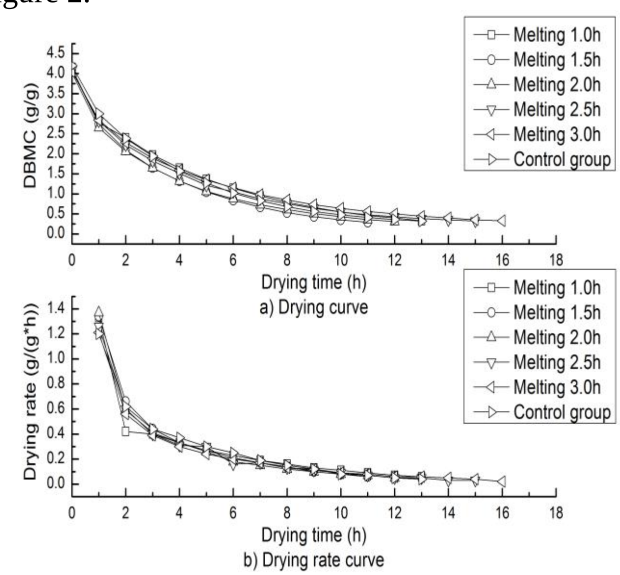

Figure 2. Effect of different melting time of freeze-thaw pretreatment on drying time and drying rate

As can be seen in Figure 2(a), along with the increase in melting time, results showed the drying time of slices firstly decreased and then increased. When melting time was 1.5h, there was a minimum drying time that was 11h. It may be due to the short thawing time that was only 1 hour, so the sample was not completely thawed. What's more, ablation of ice would be more and more with the increase of thawing time. As a result, the ice crystals melting might reach the best point while the melting time was 1.5h, and no damage to voids left after ice melting, which led that 1.5h melting time played a role in promoting drying. Generally, due to the very fresh fish fillets were frozen, there will be a strongly rigor mortis phenomenon after thawing in a certain period of time , resulting in significant shrinkage deformation of fish tissue , which might cause the ice pore to be blocked again (Coleen et al., 2012; Xiufang et al., 2012). However, with the further increase of the melting time, the rigor mortis of backwardness may be more obvious, so excessively extend melting time would lead that the drying process was inhibited.

As can be seen from the drying rate curve in Figure 2(b), for the samples of the freeze-thawing pretreatment with different melting time, there was a great difference between the first 1 hour's drying rate, and the drying rate of 2h's melting time was the maximum, while the drying rate of 3h's melting time was the minimum, which were all higher than those of the control group. Freeze-thawing pretreatment promoted the water escape of the drying section, so that the water loss rate of initial drying period would greatly increase.

3.3. Drying curve and drying rate curve of different freezing temperature

Fixed freezing time was 1.5, thawing time was 2.0h and melting temperature was 25°C. Under this condition, freeze-thawing pretreatment of fish fillets were carried out in different freezing temperature (-50°C, -40°C,-30°C, -20°C and -10°C respectively), to investigate the effects of different freezing temperature on the drying time of fish fillets, the results were shown in Figure 3.

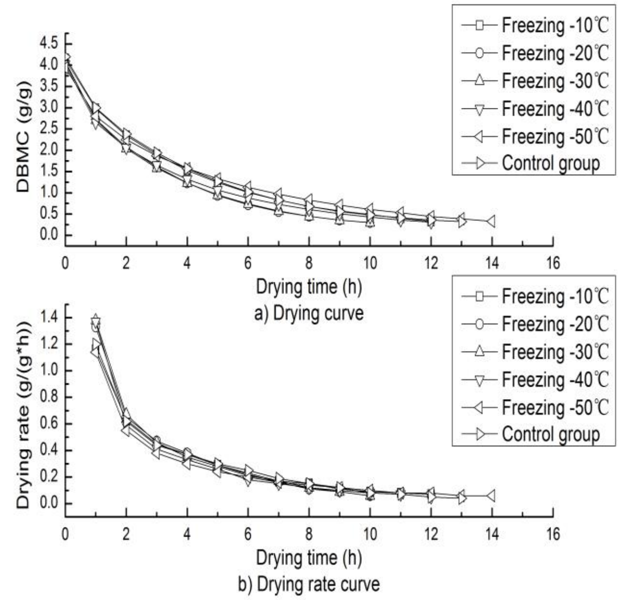

Figure 3. Effect of different freezing temperature of freeze-thaw pretreatment on drying time and drying rate

As can be seen in Figure 3a, compared with the control group, the fish fillets drying time did not have an improvement when the freezing temperature was too high or too low. On the contrary, under the condition of -50°C freezing temperature, the drying time of samples was slightly longer than that of the control group. And when the freezing temperature varied from -20°C to -30°C appropriately, fish had the shortest drying time 10h.

During freezing initial period the water among cells formed ice crystals firstly when the fish fillets were at an increasingly low temperature. Because the freezing point of water inside the cells is lower so this water remained liquid. Moreover, under the condition of steam pressure difference, the moisture inside the cell would spread out of the cells and make cell shrink .At the same time, the ice growth in the freezing process would produce extrusion, drag and drop even amyxis of fish fillets thus, the structure was brittle and the water would be lost after being re-warmed which were conducive to dehydration after freeze-thawing tilapia fillets. But higher freezing temperature may not make the water of organization completely frozen. At this time, ice crystal formation was weak, which might explain why the drying time of samples was longer at -10ºC freezing temperature than a lower temperature after the freezing pretreatment, and why the drying time was shorter at the temperature of -20ºC ~ -30ºC. In unidirectional freezing process, for one, advancing ice crystals squeezed out the free water of the tissue, and for another, they would gradually stripped adsorbed water and bound water. Under the freezing conditions at -50ºC, faster cooling rate that can make the low temperature quickly pass through the maximum frozen crystal creating belt would lead that the quantity of ice crystal formation is big and the volume is small, and that bound water and adsorbed water was frozen before being stripping from the proteins and other macromolecules (Delgado et al., 2005). Therefore, the over low freezing temperature is not conducive to drying process after melting. Their drying rate curve can be seen as Figure 3b. As can be seen from the drying rate curve in Figure 3b, for the samples of the freeze-thawing pretreatment with different freezing temperature, there was a great difference between the first 1 hours of drying rate, it was easy to find that the drying rate of -30ºC freezing temperature was the maximum, while the drying rate of -50ºC freezing temperature was the minimum. Compared with the control group, the drying rate of -10ºC and -50ºC freezing temperature was lower. Frozen impermeable or excessive freezing is the cause of this result.

3.4. Drying curve and drying rate curve of different melting temperature

Fixed freezing time was 1.5h, thawing time was 2.0h and freezing temperature was -40ºC, under this condition, freeze-thawing pretreatment of fish fillets were carried out in different melting temperature of 5ºC, 10ºC, 15ºC, 20ºC and 25ºC respectively, to investigate the effects of different melting temperature on the drying time of fish fillets, the results were shown in Figure 4.

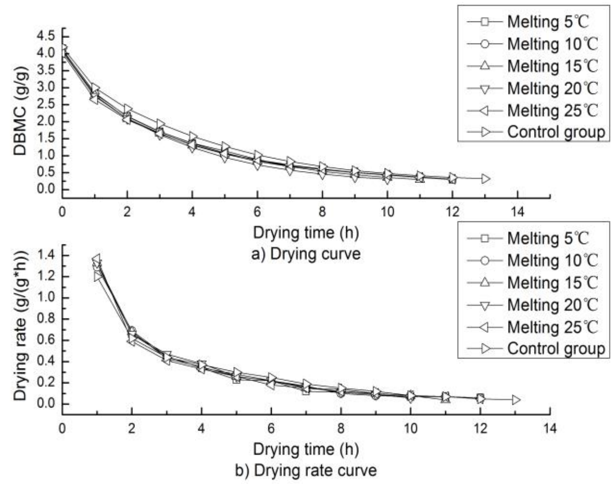

Figure 4. Effect of different melting temperature of freeze-thaw pretreatment on drying time and drying rate

The drying time of the tilapia fillets using different melting temperature treatments was shorter than that of the control group without freeze-thawing pretreatment which was shown in Figure 4. And when the melting temperature was lower than 25ºC, with the increasing melting temperature, the drying time got shorter, which explained that in a certain range of temperature, a higher the melting temperature was more beneficial to be dried. But when the melting temperature reached 25ºC, the drying time increased. In fact, the lower the melting temperature is the less quality loss will get after thawing meat. However, the higher melting temperatures will cause the muscle fibers to form larger pores, and result in greater and more extensive destruction of tissue morphology (Boonsumrej et al., 2007). At 0ºC the thermal conductivity of water is only about a quarter of the thermal conductivity of ice, so if the melting temperature is too low, these may lead that outside heat can not be sufficiently passed through the thawed layer towards inside food in a shorter defrosting time (Morenoa et al., 2013) and therefore this thawing can not play a full role in the thawing process that led to changes in the organizational structure and removal action of moisture. In addition, the lower temperature after thawing was, the lower internal temperature of the sample during initial drying time was, and water evaporation was difficult to be evaporated.

4. Conclusions

The factors in the freezing and thawing process including the frozen time, frozen temperature, melting temperature and melting time effect the drying time of the heat pump drying of Tilapia. And corresponding to the different drying stages, there exist different drying rates. When the fish fillets were operated by freeze-thawing pretreatment before drying with other conditions the same, the impact of 1.0 h freezing time for drying rate is the best, -20 ~ -30°C freezing temperatures is the best, 1.5 h melting time is the best, and 20°C melting temperature is the best in the range of this experiment. In a word, it can be seen that a suitable freeze-thawing condition pretreatment can quickly improve their dried speed, shorten the drying time.

5. References

Boonsumrej, S., Chaiwanichsiri, S., Tantratan, S., et al. (2007). Effects of freezing and thawing on the quality changes of tiger shrimp (*Penaeus monodon*) frozen by air-blast and cryogenic freezing. *Journal of Food Engineering*, 80, 292-299.

Delgado, A. E., Rubiolo, A. C. (2005). Microstructural changes in strawberry after freezing and thawing processes. *Swiss Society of Food Science and Technology*, 38, 135-142.

Duan, Z.H., Liang, L.N., Wang, J.L., et al. (2011). Drying and quality characteristics of tilapia fish fillets dried with hot air-microwave heating. *Food and Bioproducts Processing*, 89, 472-476.

Goh, L.J., Othman, M.Y., Mat, S., et al. (2011). Review of heat pump systems for drying application. *Renewable and Sustainable Energy Reviews*, 15, 4788-4796.

Guan, Z.Q., Wang, X.Z., Li, M., et al. (2013). Mathematical Modeling on Hot Air Drying of Thin Layer Fresh Tilapia Fillets. *Polish Journal of Food and Nutrition Science*, 63, 25-34.

Guo, T., He, X.Y., Dong, F.M. (2013).Hot air drying characteristics and dynamics for freeze-thaw sweet potato. *Food and Machinery*, 29,8-11(in Chinese).

Kituu, G.M., Shitanda, D., Kanali, C. L., et al. (2010). Thin layer drying model for simulating the drying of Tilapia fish (Oreochromis niloticus) in a solar tunnel dryer. *Journal of Food Engineering*, 98, 325-331.

Leygonie, C., Britz, T. J., Hoffman, L. C. (2012). Impact of freezing and thawing on the quality of meat: Review. *Meat Science*, 91, 93-98.

Li, M., Guan, Z.Q., Liu, L. (2008). Optimization of Heat Pump Drying Process of Tilapia Fillet by Secondary Multiple Regression Analytical Method. *Journal of Refrigeration*, 32, 58-62.

Morenoa, F. L., Roblesa, C.M., Sarmientoa, Z., et al. (2013). Effect of separation and thawing mode on block freeze-concentration of coffee brews. *Food and Bioproducts Processing*, 91, 396-402.

Ramirez, C., Troncoso, E., Munoz, J. et al. (2011). Microstructure analysis on pre-treated apple slices and its effect on water release during air drying. *Journal of Food Engineering*, 106, 253-261.

Sismotto, M., Paschoal, J.A.R., Teles, J.A. et al. (2014). A simple liquid chromatography coupled to quadrupole time off light mass spectrometry method for macrolide determination in tilapia fillets. *Journal of Food Composition and Analysis*, 34, 153-162.

Sow, L.C., Yang, H.S. (2015). Effects of salt and sugar addition on the physicochemical properties and nanostructure of fish gelatin. *Food Hydrocolloids*, 45, 72-82.

Wang, Y.C.H. (2009). Research on efficiency of sludge sedimentation and dewatering with natural freezing/thawing treatment. *Master's degree thesis of Suzhou University of Science and Technology*. (in Chinese with English abstract)

Xia, X.F., Kong, B.H., Liu, J. et al. (2011).

Influence of different thawing methods on physicochemical changes and protein oxidation of porcine longissimus muscle. *LWT - Food Science and Technology*, 46, 280-286.

Xiao, H.W., Gao, Z.J., Lin, H. et al. (2010). Air impingement drying characteristics and quality of carrot cubes. *Journal of Food Process Engineering*, 33, 899-918.

Zheng, M., Guan, Z.Q., Li, M., et al. (2014). Effect of pretreatment on the protein denaturation of dried tilapia fillets. *Science and Technology of Food Industry*, 34, 103-111. (in Chinese with English abstract)

Acknowledgments

The authors acknowledge the financial support from the Natural Science Foundation of Guangdong Province with grant no. 2015A030313613 and The Science and Technology Department Project of Guangdong Province with grant no. 2013B090800021.