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Effect of Physical Osmosis Methods on Quality of Tilapia Fillets Processed by Heat Pump Drying

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Key words: trehalose, ultrasound, osmosis methods, heat pump drying, fish fillet, quality parameters

In order to achieve the influence of different pretreatment methods on heat pump dried tilapia fillets, the effects of trehalose, ultrasound-assisted and freeze-thaw cycle assisted osmotic dehydration on the color, rehydration, texture and Ca^{2+}-ATPase activity were investigated. Tilapia fillets (100 mm length × 50 mm width × 5 mm height) were first osmoconcentrated in a trehalose solution combined with 4°C under atmospheric pressure for 1 h, different power of ultrasound and freeze-thawing respectively, then heat pump dried. The results showed that under the same drying method, the comprehensive score of ultrasound in 400 Watt was best, compared to freeze-thaw, the ultrasound pretreatment had a significant ($p<0.05$) effect on the color and Ca^{2+}-ATPase activity, but had no significant ($p>0.05$) effect on the rehydration and texture. However, both of them significantly ($p<0.05$) affected the quality in comparison to that of osmosis at 4°C. It indicates that suitable ultrasonic pretreatment conditions improve the quality of dried products effectively and the conclusion of this research provides reference for heat pump dried similar products.

INTRODUCTION

Fresh aquatic products due to the high moisture content can easily undergo spoilage because of microbes and enzymes, freezing and drying methods commonly used for processing. Drying method is very popular because of its simple storage conditions, long period of storage, convenient use and unique flavor and texture of dry product. Drying is regarded as an important method of food preservation [Lewicki, 2006; Deng & Zhao, 2008]. Heat pump drying is an alternative method in the food industry [Deng *et al.*, 2011]. However, it results in unfavorable changes in color, low rehydration rate, texture and flavor of food [Hu *et al.*, 2006]. In addition, the simultaneous mass and heat transfer process accompanied by physical, chemical and phase change transformations also causes it energy intensive and consequently cost intensive [Fernandes & Rodrigues, 2007]. Therefore some pre-treatment methods are applied to reduce the initial water content or modify the tissue structure in the way that the time of heat pump drying is shortened [Fernandes & Rodrigues, 2007; Nowacka *et al*., 2014].

Osmotic dehydration (OD) pretreatment prior to drying is adopted to remove the moisture from dried material [Cataldo *et al*., 2011]. In the process of OD, semi-permeable membrane is being formed as a consequence of cell membrane internal and external pressure difference. The solution runs into the free space of tissue while the water comes out of the cells [Souraki *et al.*, 2013; Derossi *et al.*, 2015]. Thus, OD pretreatment not only improves product quality but also reduces energy consumption [Mandala *et al.*, 2005; Fathi *et al.*, 2011].

Ultrasound (US) is considered as a mechanical wave with a frequency from 20 kHz to 100 MHz that can propagate in solid, liquid and gaseous medium. Power ultrasound, in a frequency range of 20 kHz to 1 MHz, is widely used in food processing because of its physical and chemical properties [Bhaskaracharya *et al.*, 2009; Rodríguez *et al.*, 2014]. Ultrasound waves rapidly generate a series of alternative compressions and expansions, similar as with a repeatedly squeezed and released sponge, which is therefore called “sponge effect”. This effect creates microscopic channels which enhance moisture removal. Moreover, ultrasound leads to cavitation which is helpful to remove attached moisture [Fernandes & Rodrigues, 2007]. As a pretreatment method, ultrasound is widely used for fruits like Malay apple, apple, strawberry [Oliveira *et al.*, 2011; Nowacka *et al.*, 2012; Gamboa-Santos *et al.*, 2014] and for vegetables [Schössler *et al.*, 2012a,b] as well.

The general approach of a freeze-thaw (FT) cycle is to freeze in a cryopreservation box, thaw in an incubator, and the effect of cycles to the change in the structure or other properties is observed. The current state of research in FT stability is based on some related empirical studies. An understanding of microstructural changes during freezing and thawing in the drying process has been implied in biological samples [Mittal *et al.*, 2013] and food [Zielinska *et al.*, 2015]. For this reason, FT is likely regarded as one of the pretreatment methods that enable avoiding the effect of high temperature and promote high moisture transfer during drying.

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The research of the method of osmotic treatment is mainly concentrated on fruits and vegetables at present, there are few reports on the research of aquatic products.

The objective of this study, with the tilapia fish used as raw material, was to investigate the effect of OD, US and FT pretreatment on the quality of the heat pump dried tilapia fillets, including color, rehydration rate, texture and Ca2+-ATPase activity. These intend to provide better technique and technology for improving the performance of the heat pump drying of tilapia fillet, as well as to provide reference for the optimization of the same aquatic products with low temperature drying process.

MATERIALS AND METHODS

Sample preparation

Fresh tilapia fillets were purchased from a local supermarket in Zhanjiang, China, whose weight was about 1.5 kg each. At the laboratory, they was cut into sheet (100 mm length × 50 mm width × 5 mm height, weight of about 30 g). Finally, the sheets were blotted with filter paper and weighed. The average initial moisture content of the tilapia fillets was 5 kg/kg in dry matter (d.m.) or 80% in wet basis.

Osmotic dehydration (OD) pretreatment

According to the pre-experimental results, to determine mass, the concentration of trehalose solution was 5% and the material liquid ratio was 1:10. Tilapia fillets were immersed into 5% trehalose solution at 4°C in a refrigerator (BCD-225SDCW, Haier, China) for 1 h. The ratio of osmotic solution to tilapia fillets was selected at 10:1 (mL/g) in order to avoid excessive dilution of the osmotic solution during the process. After the process of OD, the samples were taken out, blotted with paper towel, weighed and then dried in a heat pump.

Ultrasound (US) pretreatment

For ultrasound (US) treatment, the samples were immersed in 5% trehalose solution and submitted to ultrasonic waves at 200 Watt (OU-200), 250 W (OU-250), 300 W)OU-300), 350 W (OU-350), 400 W (OU-400), 450 W (OU-450) and 500 W (OU-500) power for 1 h in an ultrasonic bath (KQ-500DE, 40 KHz, Kunshang, China). The fluctuation of water temperature was controlled by circulation of water from hydrant tap and the increase of temperature was lower than 2°C during the process. The samples were then blotted, weighed and dried.

Freezing-thawing (FT) pretreatment

Freezing and thawing was conducted in a cryopreservation box (model BD-730LT-86L-I, Qingdao Haier group) and an incubator chamber (model FYL-YS-50L, Beijing Fu Yi Electrical Appliance Co. Ltd.), respectively. The concrete steps were as follows: FT treatment (-32°C for 1 h, 20°C for 1.5 h) — heat pump drying for 4 h — FT treatment (-40°C for 1.5 h, 25°C for 1 h) — heat pump drying for 3 h — FT treatment (-30°C for 2 h, 25°C for 0.5 h) — heat pump drying until 0.30±0.02 g/g dry matter. Before and after freeze-thaw treatment, the seeping water on the surface was blotted with filter paper and the mass of the samples was measured.

Heat pump drying

Heat pump drying was carried out at 45°C, air velocity of 2.5 m/s and humidity of 30% [Li *et al.*, 2011]. The dryer was pre-heated to temperature set point and then was loaded with fish fillets spread on nets in a single layer. The air flow was parallel to the screens and the drying process was continued until the dry matter of 0.30±0.02 g/g was reached. All experiments were carried out in triplicate. The samples without any pretreatment were set as the control group.

Color

The color of dried tilapia fillets was measured by using a colorimeter (CR-10, Konica Minolta, Japan) [Guan *et al.*, 2013]. It was reported as CIE L^*, a^* and b^* values, where L^* measures the lightness on 0 to 100 scale from black to white, a^* as (+) red or (-) green, b^* as (+) yellow or (-) blue [Bai *et al.*, 2013]. The total color difference was calculated according to the equation (1).

$$W = 100 - \sqrt{(100) - L^*)^2 + a^{*2} + b^{*2}} \quad (1)$$

Rehydration rate

Rehydration was carried out by immersing dried tilapia fillets in a water bath (HHS-6, Shanghai Boxun Industry & Commerce Co., Ltd, China) at 40°C for 1 h according to the modified method [Duan *et al.,* 2011]. Then, fillets were removed from water, drained and weighed. Rehydration rate (RR) was calculated as:

$$RR = (m - m_t) / m_t \quad (2)$$

where: RR is the rehydration rate of the sample, m and m_t is the weights of dried and rehydrated samples.

Texture

Texture measurements of the tilapia fillets were performed in terms of hardness at room temperature. Analysis of samples was carried out immediately after rehydration, using a Texture Analyzer (TMS-PRO, FTC, United States). Samples placed horizontally at the center of platform were compressed twice with a 5.0 mm diameter cylinder stainless steel probe with 5 s between cycles at the test speed of 60 mm/min, deformation of 50%.

Ca^{2+}-ATPase activity

Ca^{2+}-ATPase activity of the samples was measured by using Adenosine triphosphatase assay kits and total protein quantitative assay kits (Nanjing Jiancheng Bioengineering Institute).

Comprehensive score

The effect of pretreatment methods on the quality of dried tilapia fillets was calculated by the comprehensive scores with 100 points in total. The score of rehydration rate and Ca^{2+}-ATPase activity were both set at a=30 points, color and hardness both at a=20 points.

Rehydration rate, Ca^{2+}-ATPase activity and color indexes were are calculated as follows:

$$Y_i = a \times (W_i / W_0) \quad (3)$$

Hardness was calculated as follows:

$$Y_i = a \times (W_0 / W_i) \quad (4)$$

where: Y_i is the weighted score for the index; a is weight(s) of the indicators; W_0 represents the optimum value in this experiment; and W_i is the actual measured value for each test index.

Statistical analysis

All the tests were done in triplicate and the data were averaged. Analysis of variance (ANOVA) was conducted with JMP 7.0. Individual group differences were identified by Duncan's multiple range tests with the probability level set at 0.05.

RESULTS AND DISCUSSION

Ultrasound (US) pretreatment

Color

The color of dried food has a great influence on the acceptability of the product by consumers, because of the fact that the quality is evaluated based on visual impression. It directly reflects the phenomenon of biochemical, microbiological and physiological changes in the muscle tissue [De Santos *et al.*, 2007]. In the process of heat pump drying, Maillard reaction and the drying time would affect the color of the product.

As observed in Figure 1, US pretreatment had significantly affected the color of heat pump dried tilapia fillets compared with the control group ($p<0.05$). With the increase of ultrasonic power, the value of W first increased, then decreased, and 450 W was the maximum. This may be explained by the fact that appropriate power of ultrasound led to the greatest water losses and the severest cell deformation and tissue collapse during osmosis [Deng & Zhao, 2008], which could inhibit oxidant enzymes reaction during heat pump drying and reduce the drying time. Meanwhile, a trehalose solution is one of the best osmotic agents which reduces the browning reaction.

Rehydration rate

For the dried products, they can be directly consumed or further processed. But the drying causes the irreversible changes in the structure of the material. Therefore, the capacity of water absorption is reduced [Witrowa-Rajchert & Rząca, 2009]. Rehydration rate is an indicator used to evaluate instant products. Mass gain, volume increase and soluble components loss occurred simultaneously. The rehydration rate is dependent on the degree of disruption and destruction of cells and structures [Prothon *et al.*, 2003]. Therefore, the degree of physical and structural changes during drying is important.

The US-pretreated samples (Figure 2) showed a significant increase in the rehydration rate ($p<0.05$), which was in agreement with Nowacka *et al.* [2014]. The higher rehydration rate in the US-pretreated samples would be linked with changes produced by US in the microstructure. In addition, the US application led to shorter drying time which could lessen the damage to the protein structure, contributing to a greater water holding capacity. Whereas, a high power of US resulted in severest cell deformation and tissue collapse, which could explain the slightly lower rehydration rate shown in Figure 2. Similar findings were obtained by Deng & Zhao [2008] for apples.

Texture

Texture of dried samples is dependent on the behavior of cellular matrix and soluble solid phase inside the tissue, both with different interactions with water [Contreras *et al.*, 2005]. In heat pump drying, surface moisture lost rapidly, becoming stiff, forming a harder external layer on the tilapia fillets. In addition, the temperature of heat pump drying could induce denaturation of connective tissues and myofibrillar proteins (myosin and actin), leading to the sample hardening [Ortiz *et al.*, 2013].

The effects of US pretreatments on the texture of heat pump dried tilapia fillets were examined in terms of hardness. Figure 3 shows the change in hardness as a function of different power of US treatments. A significant difference was observed between pretreated and control samples ($p<0.05$). This result could be linked with the mechanical effect caused

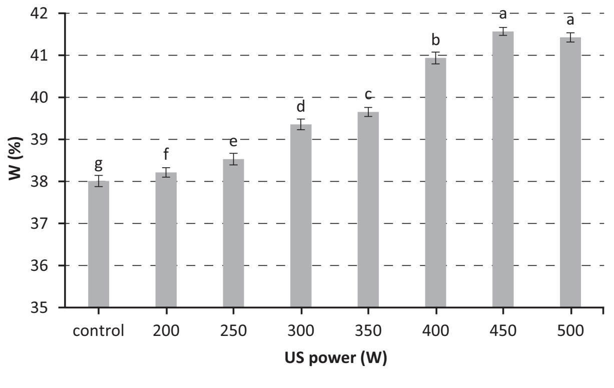

FIGURE 1. Effect of different powers of ultrasound-assisted osmosis on the color of tilapia fillets in the processes of heat pump drying.

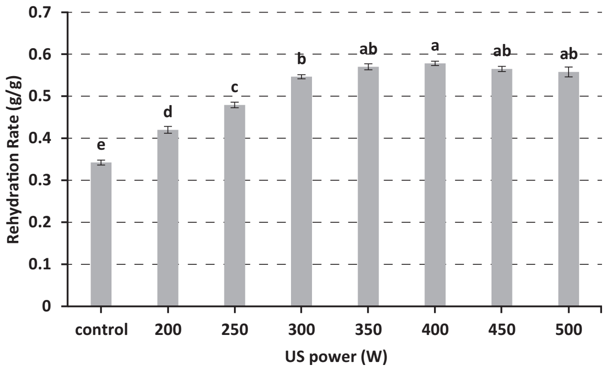

FIGURE 2. Effect of different powers of ultrasound-assisted osmosis on the rehydration rate of tilapia fillets in the processes of heat pump drying.

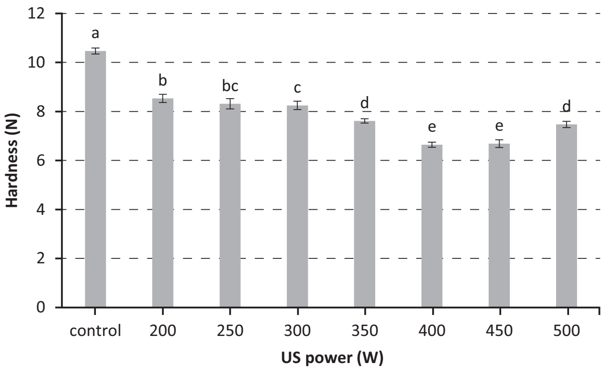

FIGURE 3. Effect of different powers of ultrasound-assisted osmosis on the hardness of tilapia fillets in the processes of heat pump drying.

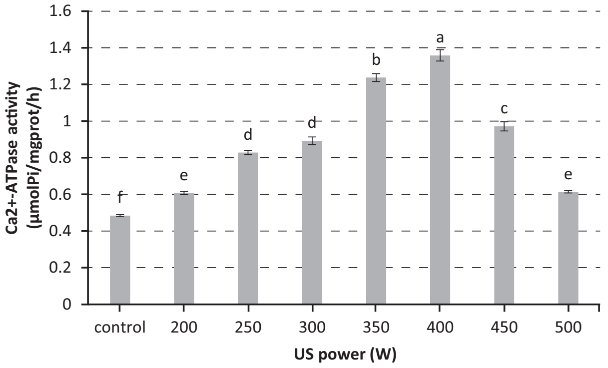

FIGURE 4. Effect of different powers of ultrasound-assisted osmosis on the Ca^{2+}-ATPase activity of tilapia fillets in the processes of heat pump drying.

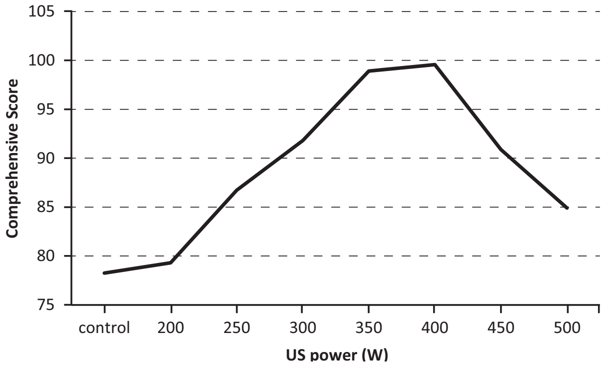

FIGURE 5. Effect of different powers of ultrasound-assisted osmosis on the comprehensive score of tilapia fillets in the processes of heat pump drying.

TABLE 1. Comparison of the effect of different pretreatment methods under the best conditions on the quality of heat pump dried tilapia fillets.

	Ca^{2+}-ATPase activity (µmolPi/mgprot/h)	W (%)	Rehydration rate (g/g)	Hardness (N)
Control	0.48 ± 0.01^{d}	38.01 ± 0.26^{d}	0.34 ± 0.01^{c}	10.47 ± 0.24^{a}
OD	1.20 ± 0.02^{c}	45.94 ± 0.26^{a}	0.47 ± 0.01^{b}	8.00 ± 0.25^{b}
US	1.36 ± 0.06^{b}	40.66 ± 0.28^{b}	0.58 ± 0.01^{a}	6.64 ± 0.21^{c}
FT	1.48 ± 0.10^{a}	39.49 ± 0.24^{c}	0.58 ± 0.01^{a}	6.58 ± 0.27^{c}

Means in the same column with different superscript letters are significantly different ($p<0.05$).

by ultrasound application. In addition, short drying time could contribute to mild damage in the protein structure, causing lesser degree of hardening, which was consistent with the previous report on dried cod [Ozuna *et al.*, 2014].

Ca^{2+}-ATPase activity

Long drying time and acoustic waves inducing compression and expansion of material cause protein denaturation, thus Ca^{2+}-ATPase activity decreased [Nowacka *et al.*, 2012]. Moreover, the infiltration amount of trehalose by the effect of US can protect the protein. Therefore, Ca^{2+}-ATPase activity is influenced by US and trehalose comprehensively.

The values of Ca^{2+}-ATPase activity for each sample are presented in Figure 4. The trend was similar to the rehydration rate, increased at first and then decreased, and the highest value was noticed at 400 Watt. In this point, the effect of US and trehalose might be gotten a balance. Before this point, less infiltration amount of trehalose and longer drying time caused by US is unlikely to prevent protein oxidation effectively. Similarly, after the point, the saturation of trehalose infiltration and the breakage of organization structure induced by US could also cause protein denaturation.

Comprehensive score

As it can be observed in Figure 5, the sample subjected to 400 W US treatment was best as regard to the comprehensive score, which was 27.25% higher in comparison with the control group.

Comparison of OD, US and FT pretreatments

The effect of OD, US and FT pretreatments, under the best conditions, on Ca^{2+}-ATPase activity, color, rehydration rate and texture was investigated and compared in Table 1. The OD-, US- and FT-pretreated samples all had significantly ($p<0.05$) higher Ca^{2+}-ATPase activity, color, rehydration rate and lower hardness than the control samples, similarly with the reports by Zou *et al.* [2013] on osmotic pretreatment for explosion puffing of dried mango chips, and by Kowalski & Szadzinska [2014] on ultrasound assisted convective--intermittent drying of cherries a well as by Zielinska *et al.* [2015] on freezing-thawing for microwave drying of blueberries. These could be linked to the effect of trehalose, microwave channels formed by US, low temperature and structure change by FT. The same, the US- and FT-pretreated samples had better quality than the OD samples.

For US and FT, there were no significant differences between rehydration rate and hardness ($p>0.05$). However, FT resulted in a significantly high sample Ca^{2+}-ATPase activity value, increased by 8.82% than in the case of US. While for whiteness, it was 2.96% higher in the US-pretreated samples than in the FT samples.

CONCLUSION

Ultrasound-assisted osmosis pretreatment could improve the quality of heat pump dried tilapia fillets to some extent, especially when the power of 400 W is better, its comprehensive score increased by 27.25% compared with the control group.

Compared to the atmospheric osmosis at 4°C, ultrasound-assisted osmosis and freezing-thawing assisted osmosis, all three methods could significantly improve the quality of tilapia fillets. However, FT resulted in 8.82% higher Ca^{2+}-ATPase activity compared to US while US caused 2.96% improvement in whiteness.

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CONFLICT OF INTEREST

Authors declare no conflict of interest.

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