

Research Article

Osmotic Dehydration Combined with Microwave Drying of Tilapia Fillets: The Impacts of Osmosis Dehydration

¹Bingyang Hu, ^{1,2}Zhenhua Duan and ¹Yan Liu

¹College of Food Science and Technology, Hainan University, Haikou 570228, Hainan,

²Hezhou University, Hezhou 542899, Guangxi, China

Abstract: Tilapia fillets were processed by osmotic dehydration combined with microwave drying. The quality aspects were compared in terms of moisture content, lightness, shrinkage, rehydration and recovery capacity. The results indicated that saline solution had superior dehydration effect and the solid/liquid ratio had no obvious impact. With the increase of osmotic concentration, time and temperature, the moisture content, rehydration ratio and recovery ratio decreased and the shrinkage ratio increased to a certain degree, while the lightness index did not change significantly. The ideal combination was that the samples were permeated in 20% saline solution with solid/liquid ratio 1:20 for 2 h at 30°C.

Keywords: Moisture content, osmosis dehydration, osmosis-microwave drying, quality indexes, tilapia fillets

INTRODUCTION

Tilapia is the common name now applied to three genera and species of fish in the family Cichlidae: *Oreochromis*, *Sarotherodon* and *Tilapia* (Duan *et al.*, 2011). Native to Africa, these species have been distributed throughout the tropical and subtropical regions and have become the world's third largest varieties in aquaculture owing to the characteristics of extensive adaptability, disease-resistant ability, miscellaneous feeding and rapid propagation. They are popular for their tender meat and superior nutritional value. Some studies have shown that the amount of the fat content in fresh tilapia meat is only 4-5%, while the protein content is up to 19.8% including rich Glu and Gly. In addition, tilapia also contains large amounts of essential vitamins, minerals and unsaturated fatty acids, especially EPA and DHA (Bellagha *et al.*, 2002; Mujaffar and Sankat, 2006; Arason, 2001). However, as the water content is up to 80%, fresh tilapia is easy to taint (Li *et al.*, 2009). Therefore, reducing enzymatic and bacterial activity is necessary and drying is an undoubtedly effective way.

Drying is one of the most general methods in food preservation, which is widely applied in developing countries. It can not only reduce water activity, prevent food from spoilage and deterioration, but also reduce weight and volume of products and make storage and transportation easier. Now, drying is the most important methods in aquatic product processing industry.

Microwave Drying (MD) has been proved to be an efficient modern food preservation technology and is

widely used in agricultural products processing (Men'shutina *et al.*, 2005; Duan *et al.*, 2003). Since the microwave heats material from interior to exterior quickly and this leads to a significant quantity of water evaporation in a short time. Due to the direction of heat transfer is same to the direction of mass transfer, different from some other drying methods, MD possesses a series of impressive features, such as rapid heating rate and high thermal efficiency. Moreover, according to Zhang and Datta (2005), it is safe, harmless and easy to control (Zhang and Datta, 2005).

Nevertheless, this process needs relatively high energy consumption, besides, the high temperature caused by microwave also influences the quality of products to some extent. Osmosis Dehydration (OD) is a process method to dry materials by immersing them in a hypertonic solution. It is characterized by a net opposite flux of water and solutes that allows the tissue of the material to become concentrated with a determined ratio solute gain/water loss, depending on process conditions (Giraldo *et al.*, 2003). Since it can be carried out at room temperature, OD obtains a series of desired attributes, such as low energy consumption, less nutriment loss and well preservation of color, flavor and structure. Hence, the traditional process has gained a renewed and increased interest, especially as a pretreatment in hybrid drying technologies (Torreggiani, 1993; Stojanovic and Silva, 2006).

Osmotic Dehydration combined with Microwave Drying (OD-MD) is an emerging method that inherits the merits of both drying processes. Through the

Corresponding Author: Zhenhua Duan, College of Food Science and Technology, Hainan University, Haikou 570228, Hainan, China

This work is licensed under a Creative Commons Attribution 4.0 International License (URL: <http://creativecommons.org/licenses/by/4.0/>).

Table 1: Nomenclature

Nomenclature	
OD	Osmotic dehydration
MD	Microwave drying
OD-MD	Osmotic dehydration combined with microwave drying
MC	Moisture content
LI	Lightness index
SR	Shrinkage Ratio
RR	Rehydration Ratio
ReR	Recovery Ratio

combination, it has been achieved high drying speed, low energy consumption and high quality without large amount of economic input (Raghavan *et al.*, 2005; Garcia-Noguera *et al.*, 2010). As now, this efficient technology has been successfully applied to berries, apples, grapes and some other fruits (Drouzas and Schubert, 1996). Compared with freeze-drying, the quality of dried strawberries produced by OD-MD showed much better (Venkatachalapathy and Raghavan, 1999). While another research focused on the effects of Osmotic Dehydration followed by Microwave-Vacuum Drying (OD-MVD) on quality of dried strawberries has demonstrated that the process did provide a better quality of dried product (Changrue *et al.*, 2008). However, now there are few reports about the application on aquatic product processing.

In the current study, the tilapia fillets osmotic conditions of OD-MD and the influence of these osmotic conditions on the moisture content and quality characteristics of tilapia fillets are studied. By this studying, it is hoped to provide theoretical guidance and scientific basis to the tilapia further processing technology (Table 1).

MATERIALS AND METHODS

Experimental procedure and design: Five replicates were performed for each batch of samples and mean value was calculated for analysis (Fig. 1).

Experimental methods:

Sample preparation: Fresh tilapias (1-1.5 kg weight, 30-35 cm length per fish) were purchased from the local fish market (Haikou, Hainan, China) and transported to the laboratory in sealed plastic containers full of ice within 20 min. The fish was cleaned, scaled, gutted and the head and tail were chopped off. Then it was skinned and cut into fillets with the thickness of 3 mm, 25 mm length×20 mm width. After rinsed by tap water, the precut tilapia fillets were placed in single layer on a stainless steel shallow dish with plastic wrap for OD experiments. The entire process should be completed within 2 h.

Solution preparation: An appropriate amount of solute was dissolved in a proper amount of distilled water according to varying osmotic conditions. The solution was prepared and kept overnight at room temperature

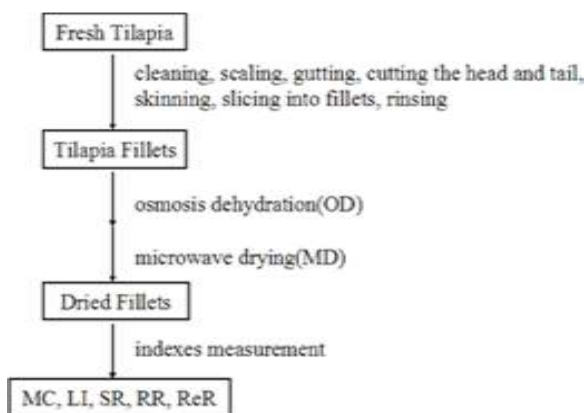


Fig. 1: The flowchart of experimental procedure and design

(25°C) to ensure osmosis media dissolving completely (Duan *et al.*, 2015).

Osmosis dehydration of fillets: Five osmotic conditions were studied. Osmosis media: sucrose and salt; Solid/liquid ratios: 1:10, 1:15, 1:20 and 1:25; Osmotic concentrations: 10, 15, 20 and 25%, respectively Osmosis time: 1, 2, 3 and 4 h; Osmosis temperatures: 10, 20 and 30°C, respectively 100(±5) g precut tilapia fillets were immersed in separate 1000 mL beakers filled with prepared osmotic solution. After the treatment of OD, the samples were gently wiped with a piece of absorbent paper in order to remove the surface moisture.

Microwave drying of fillets: The power of microwave drying oven (Model NN-C781JFS, Panasonic Co. Ltd., Japan) in this study was 300 W. Besides, the drying time and the load of samples were 3 min and 15(±0.5) g respectively. The dried samples were cooled to ambient temperature in a desiccator and then stored for moisture content, lightness index, shrinkage ratio, rehydration ratio and recovery ratio studies.

Analysis methods:

Moisture Content (MC): According to GB5009.3-2010 (GB5009, 2010), the moisture content of samples can be determined by rapid moisture analyzer (Model HB43-S, Mettler Toledo Co. Ltd., Switzerland).

Lightness Index (LI): The samples were carefully packed in transparent sealed polyethylene bags ensuring no impurity on the surface. And then, indexes of the side with better color uniformity were measured with a Color Reader (Model CR-10, Konica Minolta Co. Ltd., Japan).

In the CIELab color system, L (lightness/darkness) represents Lightness index, $L = 0$ means complete black, while $L = 100$ signifies pure white, which is the main considered index in this study. The other two referential indicators are a (redness/greenness) reflecting color saturation in red-green axis and b

(yellowness/blueness) reflecting color saturation in blue-yellow axis (Li and Duan, 2013).

Shrinkage Ratio (SR): Shrinkage is a common phenomenon in drying process of meat and shrinkage ratio is most often used to evaluate the extent of shrinkage. It was calculated in terms of percentage of volume change by Volscan Profiler (Model Volscan Profiler-300, Stable Micro System Co. Ltd., Britain). The calculation formula is:

$$R_s = \frac{V_0 - V_t}{V_t} \times 100\% \quad (1)$$

where,

R_s : The shrinkage ratio of the sample

V_0 : The initial volume of the sample before MD

V_t : The volume of the dried sample (Li and Duan, 2013)

Rehydration Ratio (RR): Rehydration capacity is a useful quality index to research the capacity of dried product capturing moisture (Changrue *et al.*, 2008). The dried samples were put into a constant temperature water bath (Model HH-S26s, Jintan Zhongda Instrument Plant, China) maintaining 40°C for 30 min after weighed in the electronic balance (Model EL204, Mettler Toledo Co. Ltd., Switzerland). Afterwards, the rehydrated samples were gently wiped with a piece of absorbent paper to remove the surface water and weighed once again. The rehydration ratio was calculated by using Equation:

$$R_f = \frac{m_f - m_g}{m_g} \times 100\% \quad (2)$$

where,

R_f : Rehydration ratio (%)

m_f : The heavy of fillets after rehydration (g)

m_g : Dried fish weight (g) (Duan *et al.*, 2011)

Recovery ratio (ReR): Recovery ratio signifies the capacity of rehydrated products recovering to the initial state. The formula to calculating recovery ratio is as following:

$$K_f = \frac{m_f}{m_x} \times 100\% \quad (3)$$

where,

K_f : The recovery ratio of the sample

m_x : The weight of the fresh sample before drying (Duan *et al.*, 2006).

RESULTS AND DISCUSSION

Effect of different osmosis media to moisture content and qualities of dried tilapia fillets: Fresh tilapia has relatively high moisture content. After the OD-MD process, the moisture reduced significantly and the flesh of fish became crisp. Figure 2a shows the moisture content change of permeated and dried tilapia fillets treated with different osmosis media (sucrose and salt).

According to the pre-experiment, the average moisture content of fresh tilapia was 78.28% (RSD = 1.65). But after OD treatment, the moisture content fell to 64.12% when salt was as osmosis medium and this was significantly lower than sucrose treatment samples (67.31%). Similarly, the moisture content values after OD-MD process were also proved to be uniform with the aforementioned results that 19.41 and 34.58% corresponded to the salt and the sucrose treatments, respectively. Therefore, it is believed that the dehydration effect of salt medium is superior to the sucrose during the OD treatment.

Osmotic pressure is the main factor to affect the penetration process and solution with higher osmotic pressure possesses stronger driving force to migrate moisture. As the major component of salt, sodium chloride (NaCl) is a kind of ionic compound which can ionize abundance of ions amount to twice of its molarity in solution. However, sucrose is nonelectrolyte without any ionization. Therefore, at the same amount of substance, salt can produce relatively higher osmotic pressure and better dewatering effect than sucrose.

Figure 2b shows the quality indexes of shrinkage ratio, rehydration ratio and recovery ratio of dried tilapia fillets treated with different osmosis media. As observed in Fig. 2b, the dried samples treated by salt penetration got lower shrinkage ratio, higher rehydration ratio and slightly lower recovery ratio than the sucrose ones. It seemed to be concluded that the products immersed in salt solution was demonstrated to obtain better qualities.

The lightness index of dried tilapia fillets treated with different osmosis media was shown in Fig. 2c. It showed that the lightness indexes of two different test groups were similar (73.7 to sucrose; 73.3 to salt) and both were higher than that of fresh samples (57.4). The increased lightness index after drying can be attributed to protein denaturation and coagulation in the OD-MD treatment. Besides, the precipitation of white crystalline from drying tilapia fillets also contributes to the increase of lightness index.

Synthesizing the results in Fig. 2, the test groups with salt medium possessed better dehydration effect and quality characteristics. Hence, salt was chosen to be the osmosis medium in following experiments.

Effect of varying solid/liquid ratios to moisture content and qualities of dried tilapia fillets: The effect of solid/liquid ratio on permeated and dried

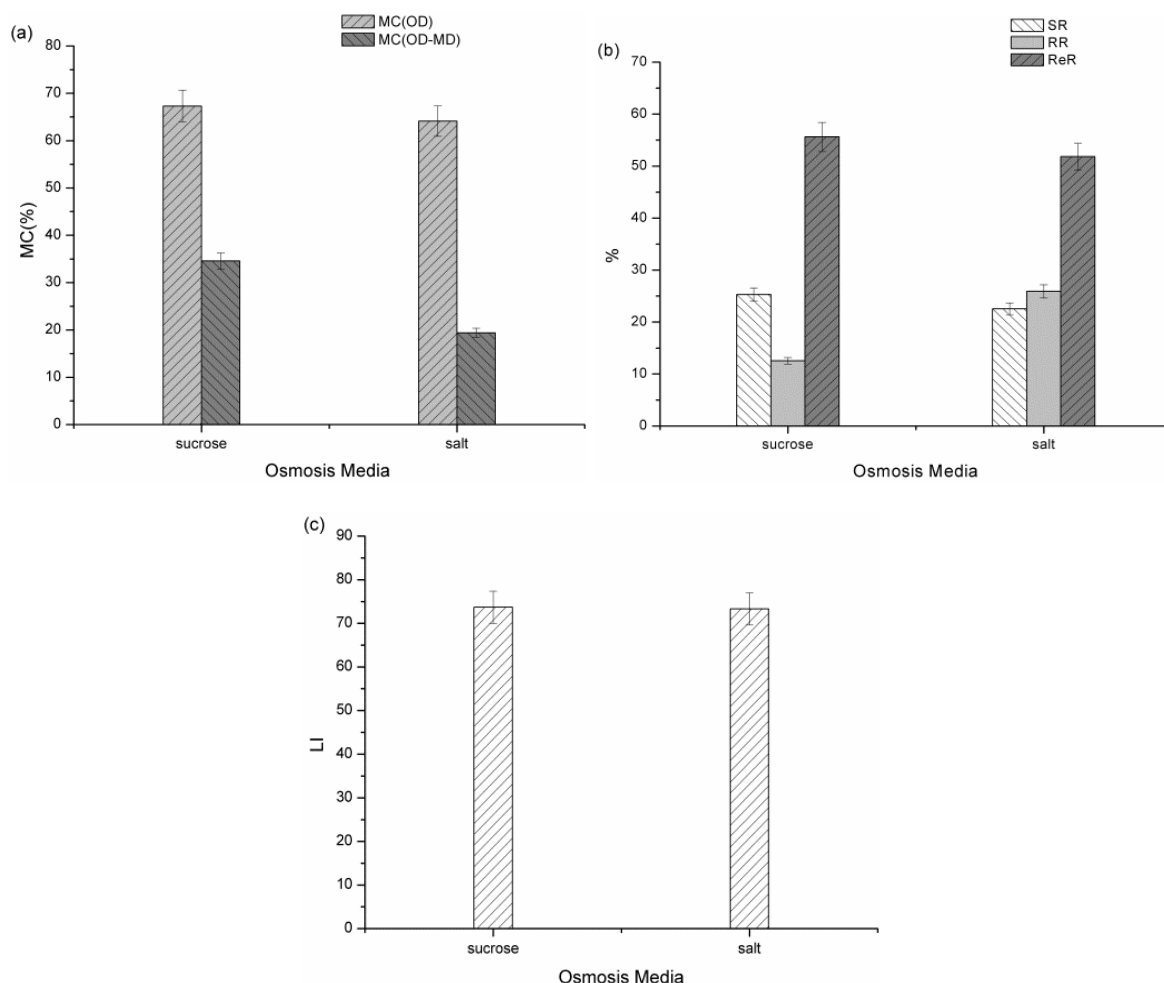


Fig. 2: Effects of osmosis media on moisture content; (a): Shrinkage ratio, rehydration ratio recovery ratio; (b): and lightness index; (c): of tilapia fillets permeated in 20% solution with solid/liquid ratio 1:20 for 1 h at 30°C

tilapia fillets moisture content is shown in Fig. 3a. As can be seen, the variation of the moisture content was fairly small.

The main reason might be the solid/liquid ratio values are lower than the point that would significantly affect the permeation process. When the solid/liquid ratio is relatively high, water exuding from samples would exert slight dilution effect on the solution, which results in slightly decreasing of osmotic pressure and finally influences the samples dehydration to a certain extent. Nevertheless, with the decreasing of the solid/liquid ratio, the dilution effect from the exuding moisture gradually recedes until it can be ignored when the ratio drops down to 1:10 or lower. This result was same to the study of Zhang and Cao (2004). In this work, the range of solid/liquid ratio was 1:10 to 1:25, so these solid/liquid ratios would not contribute significantly to the moisture content of the permeated and dried products.

Figure 3b and c show the effect of solid/liquid ratio on shrinkage ratio, rehydration ratio, recovery ratio and lightness index. According to these Figs, there was hardly any difference among the quality indexes

that were obtained under different solid/liquid ratios. Similar to the conclusion above, the influence of solid/liquid ratio to the permeation process can be ignored when the ratio is lower than 1:10. As a result, the solid/liquid ratio had little impact on these qualities indexes.

On the basis of the above results, it can be suggested that there was no obvious impact of solid/liquid ratio on the process of OD-MD and this agreed with the study of Xu (2011). Therefore, the solid/liquid ratio was kept with 1:20 referring to Xu's report in the following research.

Effect of different osmotic concentrations to moisture content and qualities of dried tilapia fillets: Osmotic concentration is a crucial condition of permeation process which directly determines the dehydration effect by controlling the osmotic pressure. FIGURE 4a reflects the effect of osmotic concentration on permeated and dried tilapia fillets. It is evident from Fig. 4a that the higher the osmotic concentration was, the lower the moisture content remained in permeated and dried products.

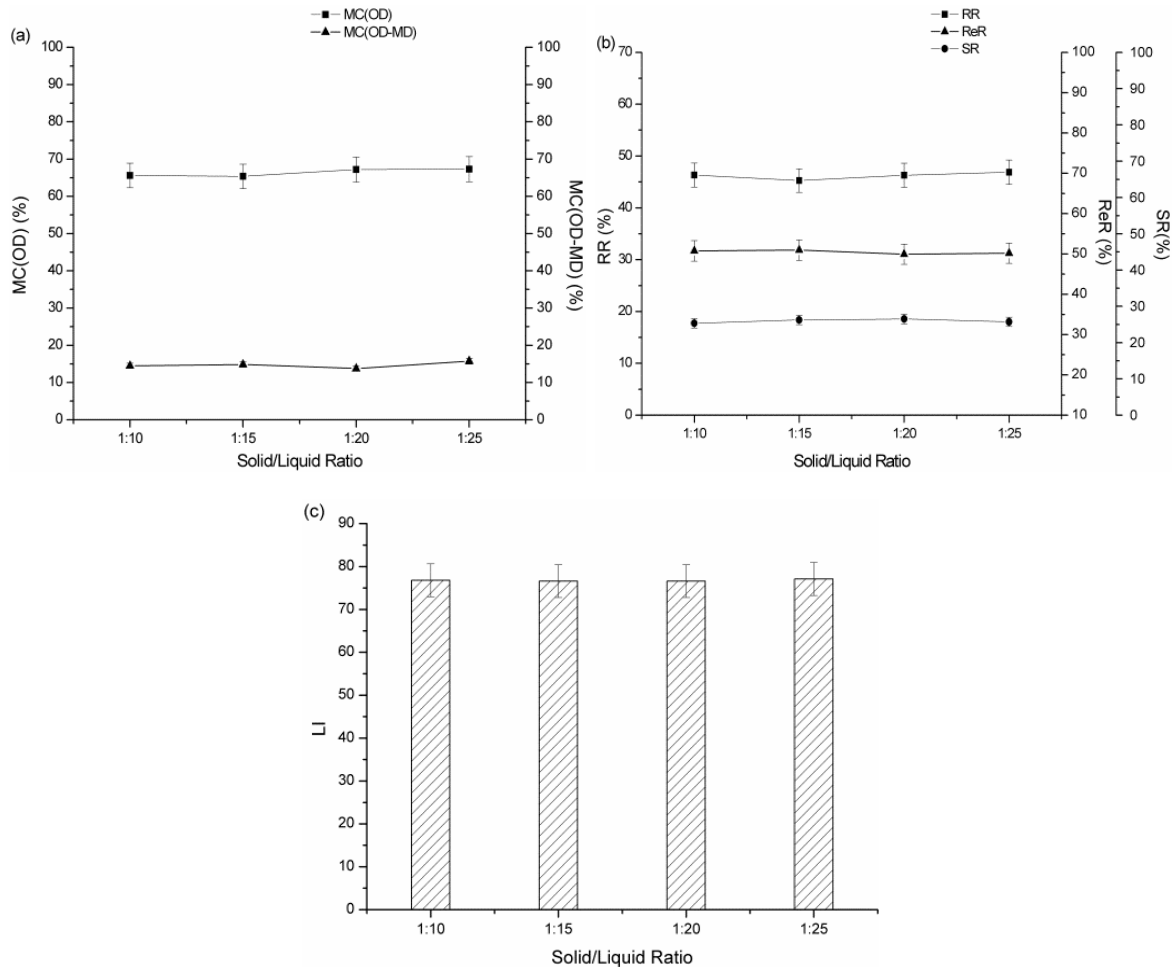


Fig. 3: Effects of solid/liquid ratio on moisture content; (a): Shrinkage ratio, rehydration ratio recovery ratio (b): and lightness index (c) of tilapia fillets permeated in 20% saline solution for 1 h at 30°C

It can be interpreted as that with the increase of the osmotic concentration, on the one hand, the osmotic pressure between solution and fish increases, which brings greater impetus of mass transfer. On the other hand, according to Fick's law, the permeation rate from fillets cell interior to surrounding solution becomes faster (Mayor *et al.*, 2006; Íspir and Toğrul, 2009). As a consequence, the products treated with higher concentration solution can get relatively lower moisture content.

Figure 4b indicates that the shrinkage ratio increased, while the rehydration ratio and the recovery ratio decreased at first and then gradually leveled off with the osmotic concentration increasing.

The reason can be explained as follow: There are two opposite mass transfer processes underway in the permeation process. One is moisture diffusion from the interior structure of samples to the exterior permeated solution; the other is solute diffusion from osmotic solution to the material internal. The extent of these two processes is depended on the osmotic pressure differences of both sides of the cytomembrane (Zou,

2012). With the osmotic concentration increasing, the osmotic pressure differences constantly increased following with more moisture and salt molecules transfer. These salt molecules decreased the porosity of samples, hindered the penetration of external moisture into internal fillet voids during the rehydration process and this subsequently reduced the capacity of rehydration and recovery of dried samples (Changrue *et al.*, 2008). Furthermore, high concentration of permeated solution may cause more moisture transfer which results in fish tissue collapse and destruction as well as a small amount of cytoplasm dissolving out (El-Aouar *et al.*, 2006). This not only increased the shrinkage ratio of the samples but also generated the decrease of the rehydration ratio and recovery ratio.

As is shown in Fig. 4c, there was hardly any change in the lightness index of dried tilapia fillets at different osmotic concentrations. The reasons are primarily as follows: It has been proved that the color change of the tilapia fillets is mainly caused by two reactions during the OD-MD process. One is the protein denaturation after heated by microwave, which

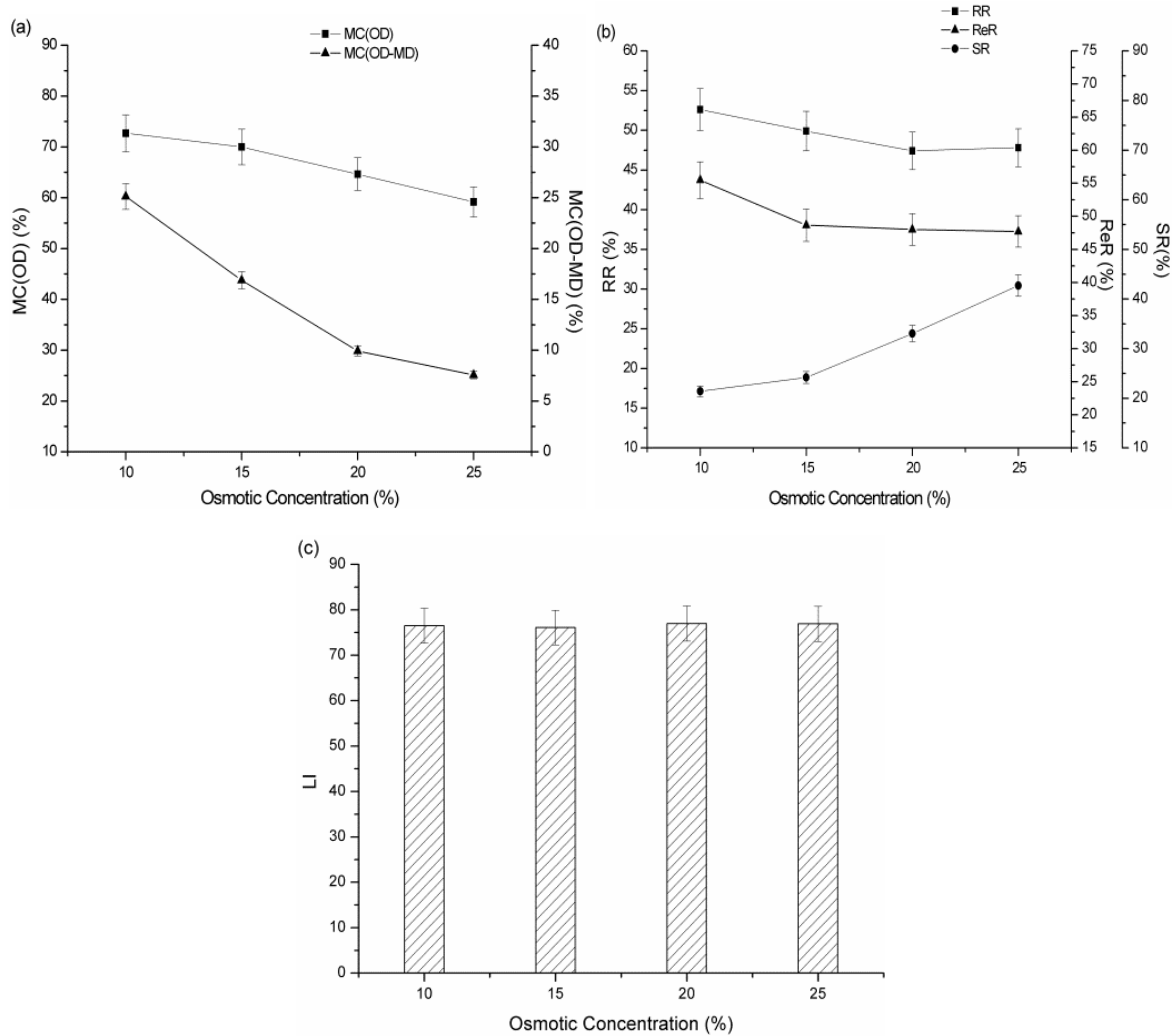


Fig. 4: Effects of osmotic concentration on moisture content; (a): Shrinkage ratio, rehydration ratio recovery ratio; (b): and lightness index; (c): of tilapia fillets permeated in saline solution with solid/liquid ratio 1:20 for 1 h at 30°C

causes product color white. The other is the Maillard reaction triggered by rich amino acids and sugars in tilapia with a high temperature brought by microwave, which causes product color brown (Yang, 2012). Nevertheless, these two reactions both have no direct relation with the osmotic conditions studied in this study. So the slightly change brought by different osmotic concentration caused no marked differences of lightness index.

Therefore, synthesizing moisture content, quality indexes including sensory quality and costs, 20% salt concentration was selected as an optimal concentration.

Effect of varying osmosis time to moisture content and qualities of dried tilapia fillets: Figure 5a shows the effect of osmosis time on moisture content of permeated and dried tilapia fillets. As can be seen, with the extension of osmosis time, the moisture content of permeated and dried tilapia fillets decreased at first and then gradually came to flat. The main reason is that, as osmosis time prolonged, the moisture inside the sample

cells diffused by degrees with the intracellular osmotic pressure increasing. Thus, the osmotic pressure differences between fish and solution decreased and finally resulted in equilibrium of the whole penetration process. When samples were permeated for 1hr, osmotic pressure differences between the two-phase of osmosis system still existed so that the dehydration process proceeded as before. However, when extended to 2 h, the pressure differences became small and the penetration process was close to equilibrium. Continuing penetration made no difference to the moisture content of the samples, whereas, it would decrease the sensory quality and nutritional quality of the products and samples was easy to be contaminated by microorganism (Zou, 2012).

Figure 5b, the effect of osmosis time on shrinkage ratio showed the trend of increase and then followed by flat. At the same time, the rehydration ratio and recovery ratio firstly decreased and then tended to level off.

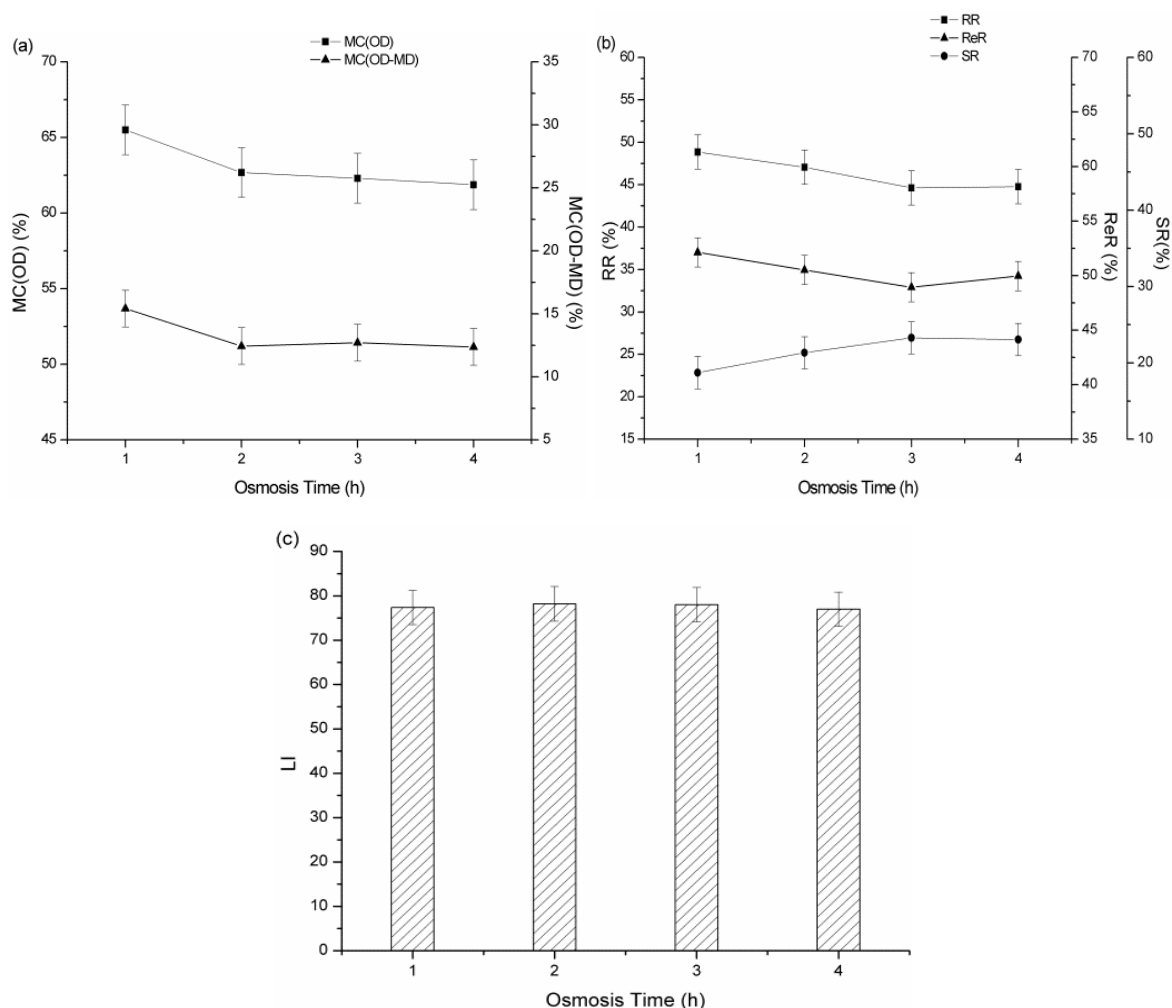


Fig. 5: Effects of osmosis time on moisture content; (a): Shrinkage ratio, rehydration ratio recovery ratio; (b): and lightness index (c): of tilapia fillets permeated in 20% saline solution with solid/liquid ratio 1:20 at 30°C

As previously mentioned, the penetration process tends to equilibrium with the extension of osmosis time. However, when the permeation process lasted too long (permeated for 3-4 h), the outermost cells were observed to be severe dehydrated with cytomembrane shrank and collapsed. Meanwhile, the cytosol such as organic acids and minerals effused as well (Wang, 2011). Consequently, the cell integrity, even the tissue structure of material was damaged. The destruction process was almost irreversible and would ultimately cause the increase of shrinkage ratio and the decrease of the other two quality indexes. In addition, some scholars believed that the reduction of rehydration ratio and recovery ratio was due to the formation of a layer of dense structure and it would impede further mass transfer (water transfer) during the rehydration process (Singh *et al.*, 2007).

The effect of osmosis time on lightness index of dried products is shown in Fig. 5c. From the figure it can be found that there was little difference between samples treated by different osmosis time. Therefore,

from the results analyzed above, 2 h was chosen as the superior osmosis time.

Effect of different osmosis temperatures to moisture content and qualities of dried tilapia fillets: Figure 6a, with the osmosis temperature increased from 10 to 30°C, the moisture content of permeated fillets slightly decreased at first and turned to be steady, while the values of dried fillets constantly reduced. The reasons might be that, the increasing of osmosis temperature would aggravate the thermal motion of ions and molecules in osmotic solution and then increase the diffusivity of the system. Therefore, the mass transfer between osmotic solution and fish was accelerated, which finally led to the reduction of moisture content (Nahimana *et al.*, 2011).

Figure 6b shows the effect of osmosis temperature on shrinkage ratio, rehydration ratio and recovery ratio of dried tilapia fillets. The figure indicates that with the increase of osmosis temperature the shrinkage ratio of tilapia increased, while the rehydration ratio and

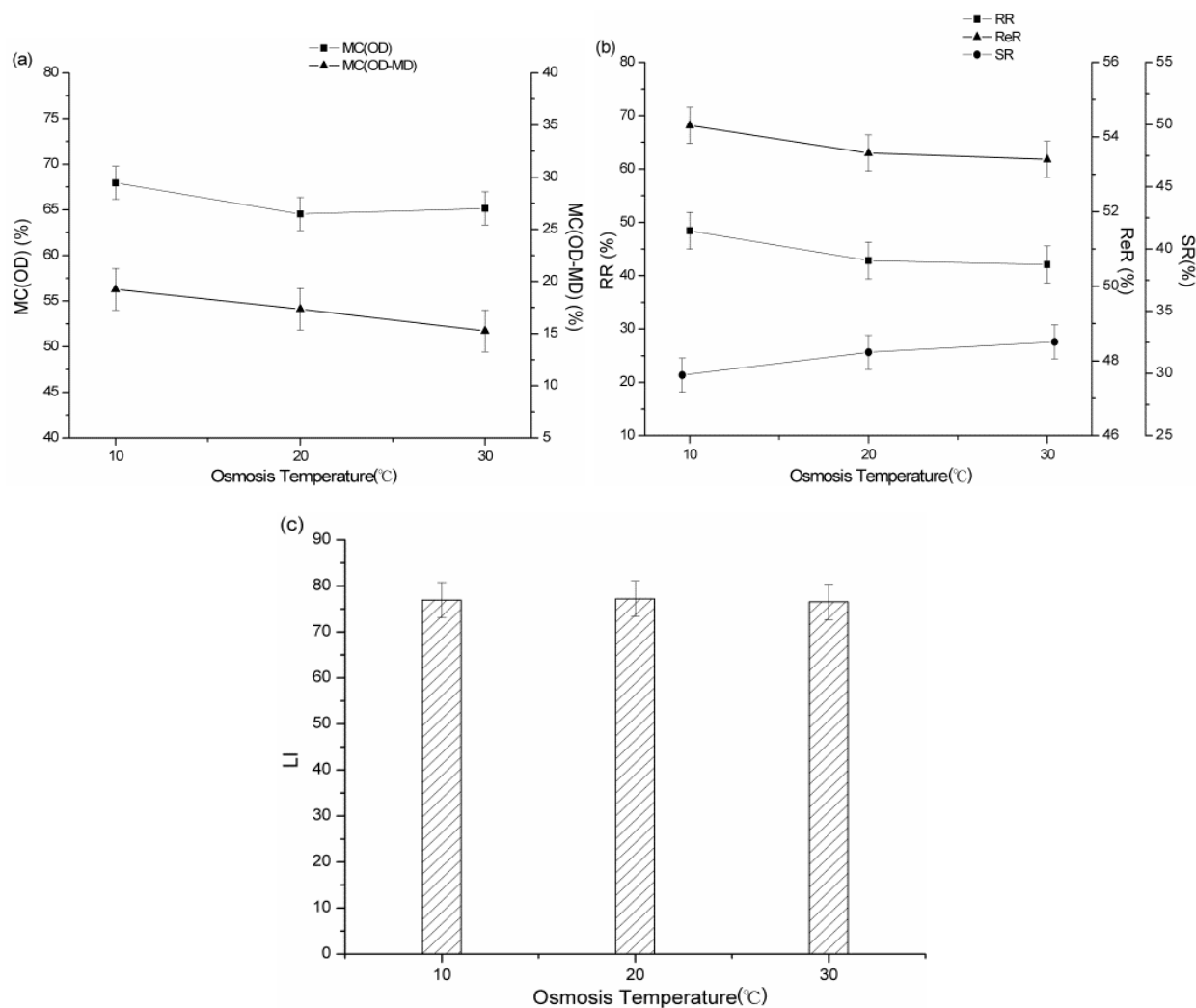


Fig. 6: Effects of osmosis temperature on moisture content; (a): Shrinkage ratio, rehydration ratio recovery ratio; (b): and lightness index; (c): of tilapia fillets permeated in 20% saline solution with solid/liquid ratio 1:20 for 1 h

recovery ratio decreased by degrees. This is because, on the one hand, the increase of temperature intensified the proceeding of mass transfer by accelerating the thermal motion of molecules, as a result, more solute accessed to the fish cells as well as more cytosol dissolved out. On the other hand, high temperature would aggravate the destruction of the fish tissue in a certain extent.

Figure 6c suggests that the osmosis temperature had scarcely any influence on the lightness index of dried products, similar with the conclusions of other osmotic conditions. Considering all results about the lightness index, it is believed that the change of osmotic conditions (including osmosis medium, solid/liquid ratio, osmotic concentration, osmosis time and osmosis temperature) has no obvious impact on the lightness index of dried tilapia fillets.

Considering the analysis results in Fig. 6, 30°C was selected to be the optimal osmosis temperature.

CONCLUSION

OD-MD process of tilapia was studied and several important osmotic conditions were researched. The osmosis medium, concentration, time and temperature all have impact on the dried tilapia fillets moisture content and quality indexes, such as shrinkage ratio, rehydration ratio and recovery ratio, while solid/liquid ratio has hardly any obvious effect. Moreover, lightness index of dried tilapia fillets does not change with the variation of osmotic conditions. Synthesizing all conditions in permeation process, it is proved that the salt osmosis medium with the osmotic concentration of 20%, solid/liquid ratio of 1:20, osmotic time of 2 h and osmotic temperature of 30°C will be the optimal combination.

ACKNOWLEDGEMENT

The authors expressed their appreciations to the financial support provided by the National Natural

Science Foundation of China (Grant No. 31360395, No.31060218) for the research work.

Conflict of interests: The Authors declare that there is no conflict of interest.

REFERENCES

- Arason, S., 2001. The drying of fish and utilization of geothermal energy, the Icelandic experience. Proceeding of 1st Nordic Drying Conference. Keynote Lectures, Trondheim, Norway.
- Bellagha, S., E. Amami and A. Farht and N. Kechauo, 2002. Drying kinetics and characteristic drying curve of lightly salted sardine (*Sardinella aurita*). Dry. Technol. Int. J., 20(7): 1527-1538.
- Changrue, V., V. Orsat and G.S.V. Raghavan, 2008. Osmotically dehydrated microwave-vacuum drying of strawberries. J. Food Process. Pres., 32: 798-816.
- Drouzas, A.E. and H. Schubert, 1996. Microwave application in vacuum drying of fruits. J. Food Eng., 28: 203-209.
- Duan, Z.H., M. Zhang and J. Hao, 2003. Preparation of crispy bighead carp slices. Sci. Technol. Food Ind., 2: 44-47.
- Duan, Z.H., J. Shang, S. Xu, X.B. Wang and M.H. Yi, 2006. Study on characteristics of hot-air drying of tilapia and its main components changes. Food Sci., 27(12): 479-482.
- Duan, Z.H., L.N. Jiang, J.L. Wang, X.Y. Yu and T. Wang, 2011. Drying and quality characteristics of tilapia fish fillets dried with hot air-microwave heating. Food Bioprod. Process., 89(4): 472-476.
- Duan, Z.H., Y.D. Wang, J.L. Wang, A.G. Feng and Y.P. Zheng, 2015. Effect of two kinds of osmotic media on quality of tilapia fillets. Adv. Mater. Res., 1081: 119-124.
- El-Aouar, A.A., P.M. Azoubel and J.J.L. Barbosa, F. Elizabeth and X. Murr, 2006. Influence of the osmotic agent on the osmotic dehydration of papaya (*Carica papaya* L.). J. Food Eng., 75(2): 267-274.
- Garcia-Noguera, J., F.I.P. Oliveira and M.I. Gallão, Curtis L. Weller, S. Rodrigues and F.A.N. Fernandes, 2010. Ultrasound-assisted osmotic dehydration of strawberries: Effect of pretreatment time and ultrasonic frequency. Dry. Technol. Int. J., 28(2): 294-303.
- GB5009, 2010. National Food Safety Standard Determination of Moisture in Foods. GB5009.3-2010.
- Giraldo, G., G., P. Talens, P. Fito and A. Chiralt, 2003. Influence of sucrose solution concentration on kinetics and yield during osmotic dehydration of mango. J. Food Eng., 58(1): 33-43.
- İspir, A. and İ.T. Toğrul, 2009. Osmotic dehydration of apricot: Kinetics and the effect of process parameters. Chem. Eng. Res. Des., 87(2): 166-180.
- Li, J., B.S. Li and W. Li, 2009. Study of tilapia pickling technique. Mod. Food Sci. Technol., 25(6): 646-649.
- Li, J.Y. and Z.H. Duan, 2013. Study on the effect of vacuum microwave drying on quality of okra. Adv. Mater. Res., 791-793: 132-136.
- Mayor, L., R. Moreira F. Chenlo and A.M. Sereno, 2006. Kinetics of osmotic dehydration of pumpkin with sodium chloride solutions. J. Food Eng., 74(2): 253-262.
- Men'shutina, N.V., M.G. Gordienko A.A. Voinovskii and T. Kudra, 2005. Dynamic criteria for evaluating the energy consumption efficiency of drying equipment. Theor. Found. Chem. Eng., 39(2): 158-62.
- Mujaffar, S. and C.K. Sankat, 2006. The mathematical modelling of the osmotic dehydration of shark fillets at different brine temperatures. Int. J. Food Sci. Tech., 41(4): 405-416.
- Nahimana, H., M. Zhang A.S. Mujumdar and Z. Ding, 2011. Mass transfer modeling and shrinkage consideration during osmotic dehydration of fruits and vegetables. Food Rev. Int., 27(4): 331-356.
- Raghavan, G.S.V., T.J. Rennie, P.S. Sunjka, V. Orsat, W. Phaphuangwittayakula and P. Terdtoon, 2005. Overview of new techniques for drying biological materials with emphasis on energy aspects. Braz. J. Chem. Eng., 22: 195-201.
- Singh, B., A. Kumar and A.K. Gupta, 2007. Study of mass transfer kinetics and effective diffusivity during osmotic dehydration of carrot cubes. J. Food Eng., 79(2): 471-480.
- Stojanovic, J. and J.L. Silva, 2006. Influence of osmoconcentration, continuous high-frequency ultrasound and dehydration on properties and microstructure of rabbiteye blueberries. Dry. Technol. Int. J., 24: 165-171.
- Torreggiani, D., 1993. Osmotic dehydration in fruit and vegetable processing. Food Res. Int., 26: 59-68.
- Venkatachalapathy, K. and G.S.V. Raghavan, 1999. Combined osmotic and microwave drying of strawberries. Dry. Technol. Int. J., 17: 837-853.
- Wang, N., 2011. The study of osmosis dehydration mass transfer kinetics and the characteristic after osmosis dehydration followed by hot-air drying of lettuce. Kunming University of Science and Technology.
- Xu, C.F., 2011. Studies on mass transfer model of tilapia fillets during osmotic process and its dehydration characteristic under osmotic and microwave. Hainan University.
- Yang, Y., 2012. Studies on vacuum-microwave drying tilapia slices. Hainan University.

- Zhang, H. and A.K. Datta, 2005. Heating concentrations of microwaves in spherical and cylindrical foods: Part two: In a cavity. *Food Bioprod. Process.*, 83(1): 14-24.
- Zhang, M. and H. Cao, 2004. The advances in food osmotic dehydration research. *Dry. Technol. Equip.*, 2(4): 3-9.
- Zou, K.J., 2012. Studies on osmotic dehydration and explosion puffing drying of mango. M.A. Thesis, Guangxi University, China.