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Effects of Osmotic Dehydration Vacuum-Microwave Drying on the Properties of Tilapia Fillets

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Abstract

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A novel drying method based on vacuum-microwave dehydration was developed to investigate the effects of different microwave gap ratios (MGR), microwave times, power densities and degrees of vacuum after osmotic pre-treatment on tilapia fillets. The results showed that the moisture value of fillets was decreased with the increased drying time, power density and vacuum degree. The shrinkage ratio, rehydration ratio and total colour change increased with elevated microwave time and power density. A high degree of vacuum was beneficial to the qualities of fillets. In conclusion, tilapia fillets retained their original quality properties after osmotically dehydrated vacuum-microwave drying (OD-VMD); optimum process parameters were MGR = 2, microwave time = 10 min, power density = 20 W/g, and vacuum degree = 0.08 MPa.

Keywords: dehydratation; drying; quality properties; tilapia; drying; water activity

Tilapia is one of the most important species of freshwater fish in China because of its varied diet, high yield and high capacity for adaptation. With its elevated levels of protein and essential amino acids (Garduño-Lugo *et al*. 2007), tilapia meat is highly prized for its high nutrition value. Tilapia output in China is enormous, with about 1.86 million tons being produced during 2016, but the activities of microorganisms and enzymes cause spoilage and result in the waste of resources (Duan *et al*. 2011). Therefore, it is important to prolong the storage period and improve the quality of tilapia.

Drying is one of the most popular preservation methods, and it is an important procedure in the processing of aquatic products. The drying of products has many advantages, such as a reduction in weight, small size, convenient storage and transportation. Dried tilapia has a long storage time and high added value. However, solar, hot-air and microwave drying methods have not been widely used in the processing of aquatic products because of low quality and high costs (Wu & Mao 2008). In addition, no single drying method is conducive to producing high-quality tilapia fillets. Osmotic dehydration (OD) is an attractive preservation method that reduces the moisture content of materials to prevent bacterial contamination (Sereno *et al*. 2001) and improves the flavour and quality of products (Mandala *et al*. 2005). Vacuum-microwave drying (VMD) combines the advantages of rapid microwave heating with vacuum drying (Calín-Sánche *et al*. 2011). Microwave treatment has the advantages of fast heating,

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high efficiency and energy saving. Vacuum heating reduces pressure as well as the boiling point of water, thereby accelerating the dehydration process. Meanwhile, the vacuum environment reduces the oxygen content and prevents the oxidative deterioration of certain components, thereby improving the quality of products. Until now, this technology has been successfully used in the processing of many agricultural products.

As a novel drying method, osmotic dehydration vacuum-microwave drying (OD-VMD) combines the advantages of osmotic dehydration (OD) technology and vacuum-microwave drying (VMD) (Ulrich & Helmar 2001), and it has been gradually implemented to increase heating efficiency and product quality (Bórquez *et al.* 2010). Therefore, in the present study, the combined OD-VMD technology was first used to monitor the quality of dried tilapia fillets and to explore an optimal approach to retain their quality.

MATERIAL AND METHODS

Fresh tilapias with weights of 500–750 g were purchased from the local fish market. The pre-treatment of tilapias was performed as in our previous report (Duan *et al.* 2011), and fillets with 3 mm thickness, 25 mm length and 20 mm width were cut.

Experiment design. The tilapia fillets were immersed in osmotic solution (20% salt and 15% sucrose) at 30°C to allow osmotic dehydration for 2 h; then, the tilapia fillets were pulled out and rinsed with distilled water. Subsequently, the fillets were carefully placed into a glass dish, and inserted into a sealed glass container with desiccants. The glass container was put into a laboratory microwave drying oven (NJL07-3; Microwave Equipment Co. Ltd., China) for continuous dehydration at different microwave gap ratios (MGR: 1, 2, 3, 4, and 5), microwave times (4, 6, 8, 10, and 12 min), power densities (10, 15, 20, 25, and 30 W/g) and degrees of vacuum (0, 0.02, 0.04, 0.06, and 0.08 MPa). The moisture content, water activity, shrinkage ratio, rehydration ratio and total colour change were determined for every batch of dried samples.

Moisture content. The moisture content of fillets was determined using a moisture meter (HB43-S; Mettler Toledo Co. Ltd., Switzerland) after drying.

Water activity. The water activity value (a_w) of fillets was determined using a portable water activity meter (HygroPalm AW1; Rotronic Co. Ltd., Switzerland).

Shrinkage ratio. The volume of fillets was measured using a volume analyser (Stable Micro Systems Volscan Profiler-300; Lotun Science Co. Ltd., UK). The shrinkage ratio (R_s) was calculated as follows:

$$R_s\,(\%) = [(V_0 - V_t)/V_0] \times 100 \qquad (1)$$

where: V_0 – volume of fillets before drying (ml); V_t – volume of fillets after drying (ml)

Rehydration ratio. Dried samples were weighed using an electronic balance (EL204; Mettler Toledo Co. Ltd., Switzerland). Dried fillets were transferred to clean warm water at 40°C to rehydrate for 30 min (Duan *et al.* 2011). Surface water was absorbed with absorbent paper and then the samples were weighed. The rehydration ratio (R_f) of the sample was calculated as follows:

$$R_f\,(\%) = [(m_f - m_g)/m_g] \times 100 \qquad (2)$$

where: m_g – weight of fillets before rehydration (g); m_f – weight of fillets after rehydration (g)

Total colour change. The total colour change of fillets was measured using a colour reader (CR-10; Konica Minolta Co. Ltd., Japan). In the CIE Lab colour system, L^* represents Lightness index, a^* reflects the colour saturation in the red-green axis, while b^* represents the colour saturation in the blue-yellow axis. Total colour change was calculated as follows:

$$\Delta E = \sqrt{(L_t - L_0)^2 + (a_t - a_0)^2 + (b_t - b_0)^2} \qquad (3)$$

where: L_0, a_0, b_0 – initial values of colour before drying, respectively; L_t, a_t, b_t – final values of colour after drying, respectively

Statistical analysis. The experimental data are presented as means ± standard deviations (SD), and the SPSS 17.0 software was used to analyse and process the experimental data.

RESULTS AND DISCUSSION

Effect of MGR on OD-VMD of tilapia fillets. MGR represents a ratio which is calculated by dividing the sum of the microwave on and off times by the on time (Gunasekaran 1999). As shown in Figure 1, the moisture value of fillets decreased rapidly from an MGR ratio of 1 to 2 and rose slowly from a ratio of 2 to 5. An MGR value of 1 denotes the lack of off time and continuous microwave drying. For example, if the total drying time is 2 min when the MGR is 1,

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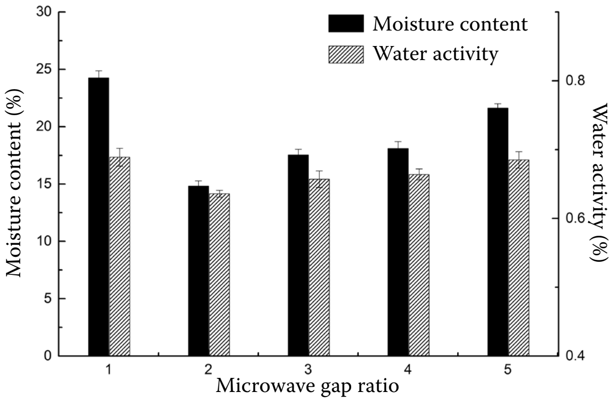

Figure 1. Effect of MGR on moisture change of tilapia fillets after osmotically dehydrated vacuum-microwave drying (OD-VMD)

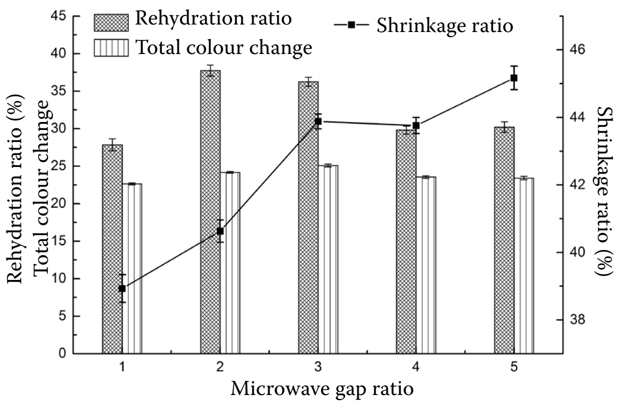

Figure 2. Effect of MGR on qualities of tilapia fillets after osmotically dehydrated vacuum-microwave drying (OD-VMD)

then the microwave is on for 2 min (no off time); when the MGR is 2, the microwave on time is 1 min, and the microwave off time is also 1 minute. As MGR increased, the off time of the microwave was gradually elongated. A comparison of MGR 1 with 2 to 5, showed that the moisture values after intermittent drying were lower than those for continuous drying. The moisture of fillets after drying reached the lowest values when MGR was 2. Because the moisture of the fillet diffuses from inside to outside and is sucked by a vacuum pump during the off time, moisture was reduced more quickly when the fillet was dried again (Baini & Langrish 2007). When the microwave oven was turned on, the fillets were heated and dried continuously. In contrast, the fillets stopped heating and absorbed the moisture within the vacuum dryer after the microwave had been turned off for a long time, so the moisture value showed a rising trend with increasing MGR (2 to 5).

With respect to the quality of dried fillets, shrinkage ratio increased gradually with increasing MGR (Figure 2). Because the fillets absorbed energy during the drying process, the temperature of samples declined slowly when the microwave turned off. The fillets shrunk and the shrinkage ratio gradually increased during off time. In addition, increasing MGR affected fillet shrinkage in terms of prolonging the off time and increasing the total time of drying.

The fillet rehydration ratio increased with an increase in MGR from 1 to 2 and decreased with a decrease in MGR from 3 from to 5. At MGR values of 1 to 2, the fillets exhibited a high degree of drying and strong ability to absorb water. The rehydration properties of fillets were improved by the formation of porous structures with strong water-holding (Zhao *et al.* 2014). Increasing MGR prolonged the off time for fillet drying. Less porous structures were formed and more moisture was absorbed from the vacuum tank when the microwave was turned off (Therdthai & Zhou 2009). This resulted in a reduced rehydration ratio.

The Maillard reaction occurred between sugars and amino acids within fillets during drying. The sensory characteristics of fillets changed during drying. The colour of fillets changed from white to pale yellow. The total colour change of fillets was more pronounced with an increase in MGR from 1 to 3 (Soysal *et al.* 2009), while a small reduction was observed when the off time of the microwave was prolonged.

Thus, tilapia fillets had the lowest levels of moisture and superior qualities when MGR was 2.

Effect of microwave time on OD-VMD of tilapia fillets. As shown in Figure 3, the moisture value of fillets was continuously reduced with increasing microwave time. Microwave energy was gathered and absorbed by fillets during the microwave drying. The binding force between fish tissue and free water was decreased, which caused moisture to evaporate rapidly and form high vapour pressure. Thus, the moisture value of fillets declined rapidly.

The shrinkage ratio was related with the moisture of fillets (Figure 4), which lost water rapidly resulting in increased shrinkage degree after microwave heating. However, the shrinkage ratio did not obviously change after 10 min of drying due to the low free water content within the fillets.

The osmotic treatment changed fillet tissue structure to a certain extent and made it more compact, so that prolonged microwave time led to an increase in the rehydration ratio of fillets (Figure 4). VMD fillets

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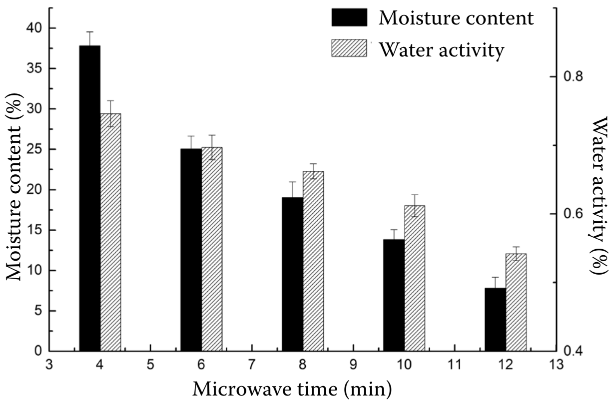

Figure 3. Effect of microwave time on moisture change of tilapia fillets after osmotically dehydrated vacuum-microwave drying (OD-VMD)

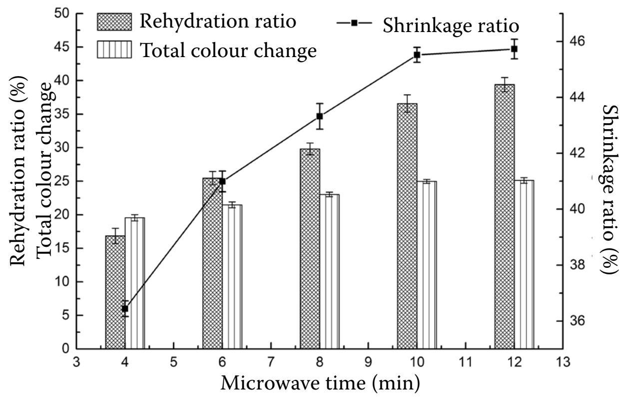

Figure 4. Effect of microwave time on qualities of tilapia fillets after osmotically dehydrated vacuum-microwave drying (OD-VMD)

formed honeycomb structures, which had good ability to absorb water during rehydration (Therdthai & Zhou 2009). In addition, protein has strong water-holding capacity and absorbs more free water, meaning that the dried product has a high rehydration ratio.

The total colour change of fillets increased with incremental increases in microwave time. From 4 to 10 min, total colour change rose gradually because fish meat contained many kinds of amino acids and absorbed the sugar during the osmotic pre-treatment. The Maillard reaction led to the colour of fillets changing from white to pale yellow and total colour change increased with microwave heating. After 10 min, further continuous heating did not result in any additional deepening of colour.

Therefore, the best drying time was 10 min since the tilapia fillets had good qualities at this time point.

Effect of power density on OD-VMD of tilapia fillets. The power density is the microwave power received by the unit mass of sample during drying. The moisture values of fillets decreased progressively with rising power density (Figure 5).

The shrinkage ratio of fillets rose gradually with increasing power density from 10 W/g to 30 W/g. Low levels of microwave energy were absorbed, meaning low levels of fillet dehydration, at the beginning of the drying time. At high power density, free water within fillets evaporated in a short time after absorbing much microwave energy (Figiel 2009), and thus shrinkage degree gradually increased (Figure 6).

Porous structures easily formed in fillets in response to VMD, and the quantity of structure formed increased with increasing power density (Adedeji *et al.* 2008). Porous structures exhibited a strong capacity to bind water during the rehydration process (Figure 6).

The Maillard reaction changes the colour of fillets in a manner which is related to the power density

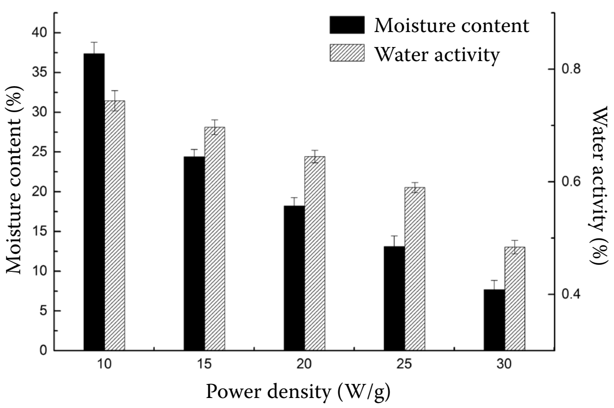

Figure 5. Effect of power density on moisture change of tilapia fillets after osmotically dehydrated vacuum-microwave drying (OD-VMD)

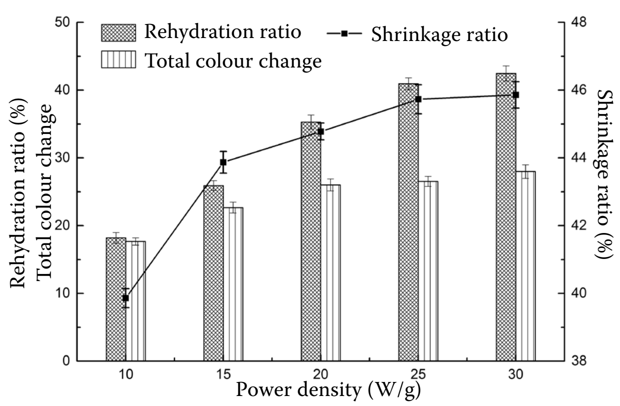

Figure 6. Effect of power density on qualities of tilapia fillets after osmotically dehydrated vacuum-microwave drying (OD-VMD)

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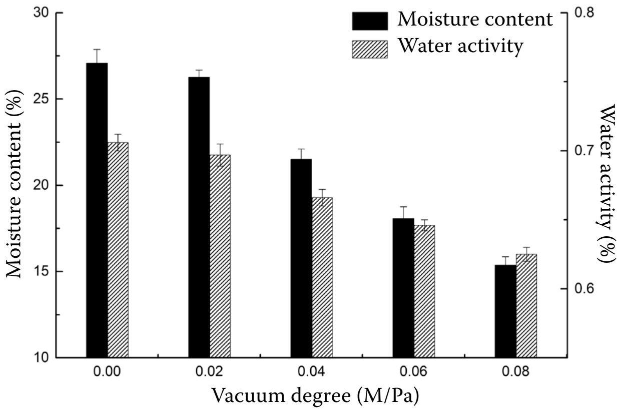

Figure 7. Effect of vacuum degree on moisture change of tilapia fillets after osmotically dehydrated vacuum-microwave drying (OD-VMD)

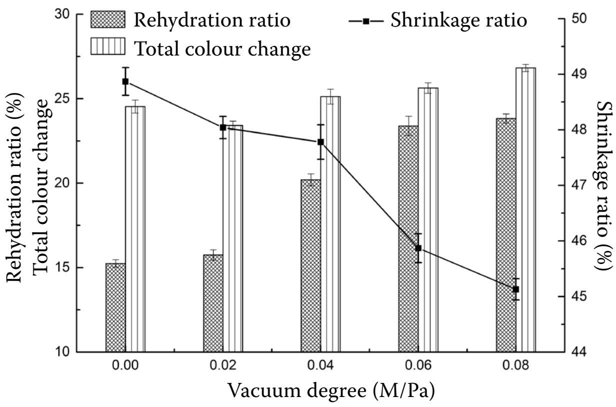

Figure 8. Effect of vacuum degree on qualities of tilapia fillets after osmotically dehydrated vacuum-microwave drying (OD-VMD)

of the microwave (Li & Duan 2013). More microwave energy was absorbed by fillets with increasing power density, leading to pronounced changes in total colour (Figure 6).

With respect to changes in fillet moisture and qualities, the best power density level was 20 W/g.

Effect of vacuum degree on OD-VMD of tilapia fillets. The moisture value of fillets decreased with increasing degree of vacuum. All other conditions being equal, increasing the vacuum degree reduces the boiling point of water (Durance & Wang 2002). Compared with low vacuum and normal pressure, the internal moisture of fillets escaped easily at high degrees of vacuum after absorbing the same microwave energy, so the moisture value of fillets was lower than in other conditions (Figure 7).

The shrinkage ratio of fillets under vacuum conditions was lower than at normal pressure (Figure 8). Fillets rapidly formed the honeycomb structure in response to VMD, and the quantity of the structure increased with increasing vacuum degree (Zhang *et al.* 2007).

The porous structure exhibited water imbibition, leading to the rehydration ratio rising in a straight line (Debnath *et al.* 2004). In addition, a high degree of vacuum elicited pronounced dehydration and extent of drying under the same conditions. Interestingly, fillet rehydration ratios were the same at vacuum degrees of 0.06 and 0.08 MPa (Figure 8).

The total colour change decreased slightly (from vacuum degree of 0 to 0.02 MPa) and then increased (from 0.04 to 0.08 MPa). The Maillard reaction and fat oxidation resulted in deeper colour under normal pressure conditions (Bai-Ngew *et al.* 2011). Vacuum conditions protected fillets against fat oxidation during drying, meaning that the Maillard reaction would be the main reason for the change in total colour under conditions of high vacuum (Figure 8).

A drying condition with a high degree of vacuum is conductive to reducing moisture and safeguarding product quality; with this in mind, the best vacuum degree was 0.08 MPa.

CONCLUSIONS

The various parameters of microwave heating had effects on the moisture and quality of tilapia fillets during OD-VMD. The moisture values of fillets after intermittent drying were lower than those achieved using continuous drying. Increasing the microwave time, power density and vacuum degree decreased the moisture value of fillets. Shrinkage ratio increased with rising MGR, microwave time and power density, but exhibited an opposite relationship with vacuum degree. The rehydration ratio and total colour change rose with increasing of microwave time, power density and vacuum degree. High degree of vacuum, low power density and shorter intermittent time were beneficial in safeguarding fillet quality.

In conclusion, the moisture of tilapia fillets was reduced effectively and the quality of the product was better after OD-VMD; the optimum process parameters were MGR = 2, microwave time = 10 min, power density = 20 W/g, vacuum degree = 0.08 MPa.

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