Dehydration property of Shrimp (*Pandalus borealis*) undergoing heat-pump drying process

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Abstract: Peeled, headed or whole shrimp (*Pandalus borealis*) was dried in a heat-pump dryer at -2–0℃ and 20℃, respectively, and desorption isotherms characterizing the dehydration property of each shrimp sample group were determined. Desorption isotherms of shrimp handled differently and dried at different temperatures (-2–0℃ or 20℃) could be well described by Oswin's model ($X = a(\frac{a_w}{1-a_w})^n$). The regression model of peeled, headed or whole shrimp was established, which is reliable for predicting the desorption isotherms of shrimp undergoing heat-pump drying. The handling methods of shrimp exhibit measurable influence on desorption isotherms of shrimp, whereas drying temperature (-2–0℃ or 20℃) has little influence on the constants of *a* and *n* in Oswin's model, of whole shrimp, even though it has certain influence on these constants of peeled and headed shrimp. For heat-pump drying, headed shrimp may have a better stability than peeled or whole shrimp due to the best stability.

Key words: Heat pump drying, shrimp (*Pandalus borealis*), dehydration property, desorption isotherm, Oswin's model
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1 Introduction

Shrimp has long been recognized as a highly priced commodity. Preservation is an important issue for shrimp because it is liable to perish. Drying has been shown to be an efficient and cheap method for food preservation. In addition to the convenience of preservation, dried shrimp also presents favorable flavor. Accordingly, dried shrimp has a long tradition of popularity in the Orient and is gaining wide acceptance in the U.S. and European markets[1].

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At present, most of the dried shrimp are produced by natural sun drying or hot-air drying, severe deterioration in quality often occur during the drying process[2,3]. In order to improve the quality of dried shrimp products, freeze drying and microwave drying have recently been employed in shrimp drying. Freeze drying is capable of achieving good quality of dried shrimp products, but it is costly and time-consuming. The production cost of freeze drying, for instance, is several times higher than that of hot-air drying[4]. Furthermore, freeze-dried products also need to be properly packaged and stored, otherwise they will deteriorate rapidly. Another drawback is that freeze-dried products are prone to lose their flavors during the drying process[5]. Microwave drying or vacuum-microwave drying offers an alternative way to improve the quality of dried products[6,7]. As microwave is characteristic of rapid heat transfer, moisture evaporation within the food is fast during microwave drying or vacuum-microwave drying due to volumetric heating. As a result, food under microwave drying or vacuum-microwave drying can be dried quickly without exposure to high temperature. However, it is essential for microwave drying or vacuum-microwave drying to control the end-point of the drying process, in case of over drying of final products[8].

Heat pump is a device that is effective in extracting thermal energy from a lower temperature source and releasing it to a higher temperature source[9]. Unlike hot-air drying, a heat-pump dryer is cost-effective as it can extract and utilize the latent energy of the air and water vapor for product drying. Meanwhile, a heat-pump dryer is capable of lower temperature drying, therefore, it is benefit for high quality shrimp products drying at relatively low cost.

As the water activity of dried food governs its physical, chemical and microbiological stability, particularly the microbial growth, lipid oxidation, non-enzymatic activity, enzymatic activity and texture of the food[6], information of water sorption isotherms is used in drying process design and prediction of drying end-point[10-12].

The objectives of this research were to determine the desorption isotherms of shrimp undergoing heat-pump drying processes, to study the models of desorption isotherms and to investigate the effect of heat-pump drying under different treatments. Evaluation is hereby given to the application of heat pump in shrimp drying production.

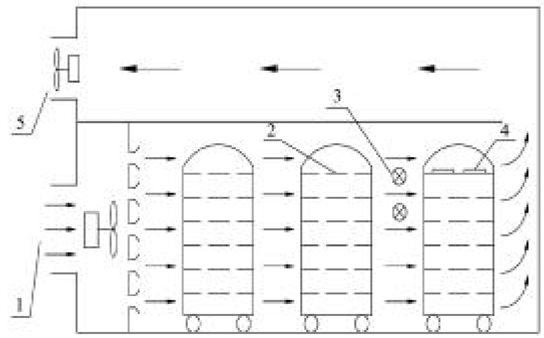
2 Materials and methods

2.1 Heat-pump dryer

Shrimp drying experiments were carried out with a batch type heat-pump dryer (designed by IFL and Seafood Bureau of Iceland, produced by Cooltech) in Gullfiskur Company (Figure 1). This heat-pump dryer has two settings of drying temperature as -2–0℃ and 20℃, and is mainly used for the production of dried haddock fillets. The dimensions of drying cabin are about 4.0 m (length)×3.0 m (width)×2.5 m (height).

2.2 Shrimp

Shrimp (*Pandalus borealis*), commercially quickly frozen on boat with the size of 98-104 counts/kg and frozen peeled shrimp with the size of 538-570 counts/kg were purchased from an export company.



1. Drying air in 2. Grid 3. Air flow rate and RH measuring points 4. Small grid 5. Wet air out

Figure 1 Schematic diagram of the heat-pump dryer

Shrimp samples used in this project were grouped into four categories: frozen peeled shrimp, thawed peeled shrimp, headed shrimp (with the size of 196-200 counts/kg) and whole shrimp. The headed shrimp was obtained by removing the head of frozen shrimp. Thawed shrimp samples were prepared by putting frozen peeled shrimp into running water of 5℃ at ambient temperature of 5–8℃ for 30 minutes and then putting them on a grid until no water dripping down. All the samples were kept in a frozen storage (at -18–20℃) before starting the experiments except for the thawed peeled shrimp.

2.3 Methods

For each experiment, 300-400 g of shrimp samples was put on a small grid (30 cm×30 cm), and 3-4 kg of the same type of samples was put on a large grid (100 cm×120 cm). All the samples on both small and large grids were scattered in a single layer. For the purpose of comparison, samples on the two grids were dried at -2–0℃ or at 20℃. During the drying procedure, the small grid was taken out every two hours when drying at -2–0℃ or every one hour at 20℃ and being weighted quickly with a digital balance (with an accuracy of ±0.5 g), then sent back into the dryer at once. At the same time, 50 g of samples was taken out from the large grid and put into a plastic bag (being fastened quickly) for water activity measurement.

2.3.1 Moisture content measurement

The initial moisture content of the samples was determined by drying about 5 g of shred shrimp in an oven at 102–105℃ for four hours according to ISO

6496(ISO1990). The changes of moisture content during the experiment were calculated based on the initial moisture content and the weight loss of the samples. The finial moisture content of dried shrimp products was within 15%-18% (w.b.). Temperature and relative humidity (RH) inside the heat-pump dryer chamber were measured and recorded automatically by HOBO U12 Temp/RH Data Logger every 5 minutes, and the air flow rate inside the chamber was measured with an anemometer (type: Testo 452).

2.3.2 Water activity (a_w) measurement

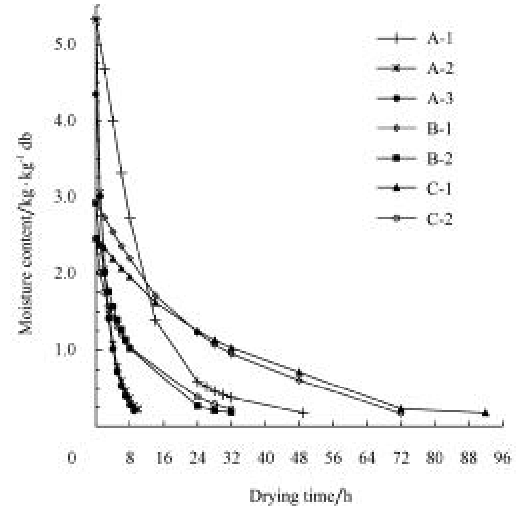
The water activity (a_w) of all the shrimp samples was measured with Novasina AW-Center (AWC503 RS-C, Axair AG, Switzerland). Three samples could be measured simultaneously in the temperature-constant (25±0.2)℃ measuring chamber of the instrument. Sensors in the chamber were previously calibrated with saturated salt solutions at four humidity reference points: RH =33%, 53%, 75% and 90%, and could measure a_w at the range of 0.06 to 1.00. The sensors indirectly registered the humidity change in the conductivity of a hygroscopic electrolyte. The samples were placed in a clean and dry plastic sample cup and analyzed in triplicate.

3 Results and discussion

3.1 Drying curves of shrimp

The initial moisture content (w.b.) of frozen peeled shrimp, thawed peeled shrimp, frozen headed shrimp and frozen whole shrimp was 84.2%, 74.5%, 71.1% and 81.4%, respectively. The air flow rate inside the heat-pump dryer ranged from 1.8 m/s to 2.2 m/s, and the RH was within 40%-60% depending on the drying temperature. The drying curves of shrimp at different drying temperatures are shown in Figure 2.

The drying of peeled shrimp at 20℃ was much faster than that at -2–0℃. It took only 9 h and 10 h for thawed peeled shrimp and frozen peeled shrimp to be dried to the final moisture content of 0.21 and 0.23 (kg water/kg dry solid) at 20℃, respectively, whereas the drying of frozen peeled shrimp at -2–0℃ required 48 h. On the other hand, the drying of headed shrimp and whole shrimp at 20℃ required nearly equal drying time of 32 h, but 72 h and 92 h were respectively needed for the above samples to be dried at -2–0℃.



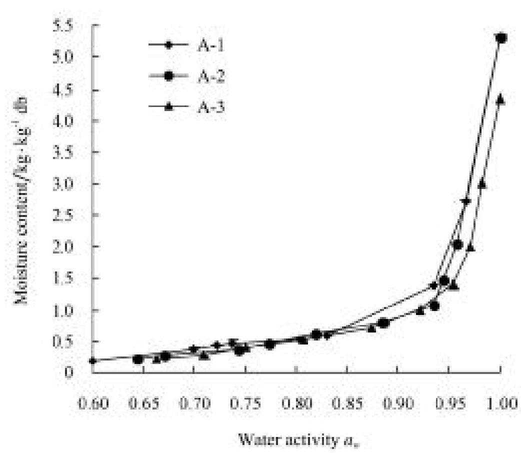
A-1: frozen peeled shrimp, -2–0℃; A-2: frozen peeled shrimp, 20℃; A-3: thawed peeled shrimp, 20℃; B-1: frozen headed shrimp, -2–0℃; B-2: frozen headed shrimp, 20℃; C-1: frozen whole shrimp, -2–0℃; C-2: frozen whole shrimp, 20℃

Figure 2 Drying curves of shrimp

3.2 Dehydration isotherm curves of shrimp

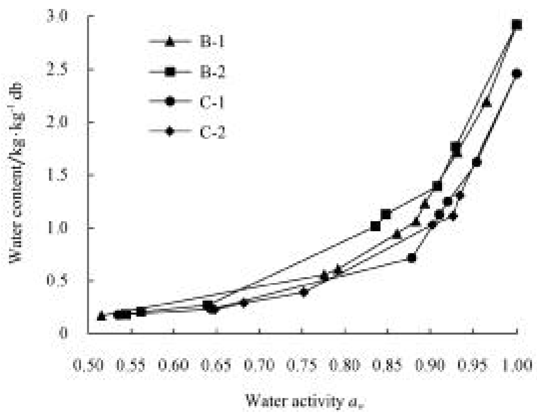
The relationship curves of moisture content and water activity of peeled shrimp (A-1, A-2, A-3), headed shrimp (B-1, B-2) and whole shrimp (C-1, C-2) were shown in Figures 3 and 4, respectively.

The peeled shrimp, either frozen or thawed, dried at -2–0℃ or 20℃ exhibited almost the same moisture content with the corresponding water activity a_w of less than 0.83 (Figure 3). However, when a_w was larger than



A-1: frozen peeled shrimp, -2–0℃; A-2: frozen peeled shrimp, 20℃; A-3: thawed peeled shrimp, 20℃

Figure 3 Relationship of moisture content and water activity of peeled shrimp handled differently and with different drying temperature



B-1: frozen headed shrimp, -2–0℃; B-2: frozen headed shrimp, 20℃;
C-1: frozen whole shrimp, -2–0℃; C-2: frozen whole shrimp, 20℃

Figure 4 Relationship of water content and water activity of frozen shrimp handled differently and with different drying temperature

0.83, the moisture content of the above samples changed differently with same water activity values. The difference was most significant between frozen shrimp dried at -2–0℃ and thawed shrimp dried at 20℃ (A-1 and A-3; Figure 3). The moisture content of A-3 was always lower than that of A-1, but maximum difference of moisture content reached 0.75 (kg/kg, db) when a_w exceeded 0.96. The desorption isotherms of headed shrimp dried at -2–0℃ and 20℃ were similar in the ranges of $a_w < 0.70$ and $a_w > 0.90$, but the moisture content of B-1 was lower than that of B-2 in the range of $0.70 < a_w < 0.90$. Additionally, the desorption isotherms of whole shrimp dried at -2–0℃ and 20℃ were quite similar within the whole measured range of a_w.

It could also be found that the moisture content of headed shrimp was higher than that of peeled shrimp and whole shrimp at the corresponding values of water activity (Figures 3 and 4). Furthermore, for peeled shrimp, headed shrimp and whole shrimp, the water activity decreased rapidly when the moisture contents dropped to 0.5 (kg/kg, db) during the drying process.

3.2 Modeling of dehydration isotherm of shrimp

In respect of modeling the dehydration isotherm of shrimp, Oswin's equation[11] was employed, which has been demonstrated applicable for describing high protein content drying products[13,14]. The equation was described as follows:

$$X = a\left(\frac{a_w}{1-a_w}\right)^n, \tag{1}$$

where X is moisture content (db), a_w is water activity in decimal, while a and n is constants.

Transforming model (1) into the following form:

$$\mathrm{Ln}(X)=\mathrm{Ln}(a)+n\ \mathrm{Ln}[(a_w/(1-a_w)]. \tag{2}$$

The values of constants a and n were generated by linear regressions of model (2) and were listed in Table 1 with the corresponding correlation coefficients (R^2). It indicated that the values of constant a of peeled shrimp, headed shrimp and whole shrimp were only in small difference, and the same was true for constant n among the above shrimp samples. It was accordingly noted that the desorption isotherms of peeled shrimp, headed shrimp and whole shrimp were not significantly affected by the handling methods and drying temperature. As a result, the mean values of constants a and n could be employed reliably to predict the relationship of the moisture content and water activity of shrimp samples in the drying process. Based on the linear regression of model (2), Oswin's models of peeled shrimp, headed shrimp and whole shrimp were established as follows:

peeled shrimp: $$X = 0.16\times\left(\frac{a_w}{1-a_w}\right)^{0.7838}, \tag{3}$$

headed shrimp: $$X = 0.1808\times\left(\frac{a_w}{1-a_w}\right)^{0.8888}, \tag{4}$$

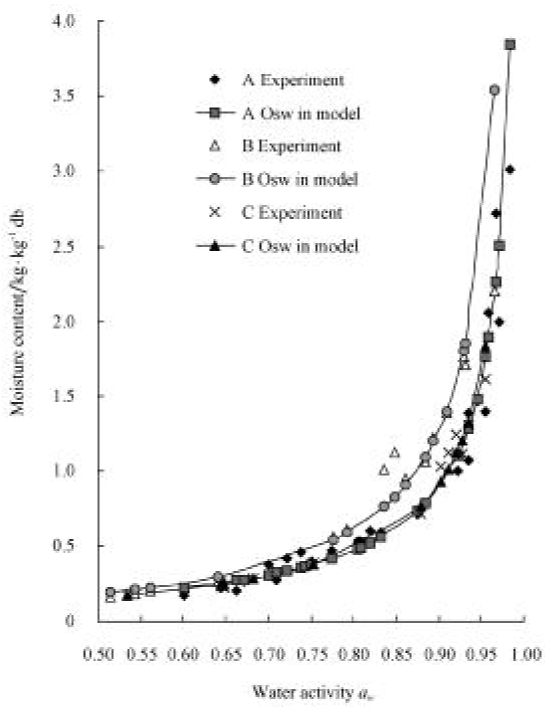
whole shrimp: $$X = 0.1539\times\left(\frac{a_w}{1-a_w}\right)^{0.8150}. \tag{5}$$

Table 1 Values of constants a and n and R^2 of Oswin's models for the desorption isotherms of various shrimp groups

Samples*	a	n	R^2
A-1	0.1673	0.8238	0.9850
A-2	0.1580	0.7884	0.9898
A-3	0.1551	0.7393	0.9917
B-1	0.1970	0.8007	0.9825
B-2	0.1660	0.9770	0.9860
C-1	1.1539	0.8084	0.9946
C-2	0.1492	0.8216	0.9953
A-average	0.1600	0.7838	0.9850
B-average	0.1808	0.8888	0.9787
C-average	0.1539	0.8150	0.9948

Note: *Legends used are the same as in Figs. 1 and 2.

Figure 5 represents the predicted curves of models (3), (4) and (5) and the experiment results with $a_w > 0.5$. It could be observed that the predicted values and experiment data of peeled shrimp and whole shrimp were in excellent agreement compared with that of headed shrimp. Additionally, the desorption isotherms of peeled shrimp and whole shrimp were in greater proximity than that of headed shrimp, which exhibited lower water activity than peeled shrimp and whole shrimp at corresponding moisture content. That is to say that headed shrimp may have better stability than peeled shrimp and whole shrimp. As the drying rate of headed shrimp was demonstrably higher than that of whole shrimp[15], it is therefore thought that the quality of heat-pump dried headed shrimp may be superior to that of heat-pump dried whole shrimp.



A: peeled shrimp; B: headed shrimp; C: whole shrimp

Figure 5 Predicted curves of Oswin's model and experiment results of peeled shrimp, headed shrimp and whole shrimp

4 Conclusions

The desorption isotherms of shrimp handled differently and dried at -2–0℃ or 20℃ in the heat-pump dryer can be well described by Oswin's model. It is applicable for the regression models being used to predict the desorption isotherms of peeled shrimp, headed shrimp and whole shrimp undergoing heat-pump drying. The handling methods of shrimp have measurable influence to desorption isotherms of shrimp, whereas the drying temperature (-2–0℃ or 20℃) has little effect on the constants *a* and *n* of whole shrimp, even though it shows small influence on those of headed shrimp and peeled shrimp. The desorption isotherms of both peeled shrimp and whole shrimp are in close similarity as compared with that of headed shrimp. As for heat-pump drying, the final quality of headed shrimp may be much better than peeled shrimp and whole shrimp due to the best stability.

Acknowledgement

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