

Improvement of Freezing Quality of Food by Pre-dehydration with Microwave-Vacuum Drying*

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Abstract

Partial dehydration by microwave vacuum drying has been applied to tuna, oyster and mackerel prior to freezing in order to reduce quality damages due to freezing and thawing. Samples were dehydrated at pressure of 4kPa and temperature lower than 25°C. Two cooling conditions were tested in the experiment by using the freezing chamber of temperatures -20°C and -80°C. The experimental results showed that decreasing the water content in tuna could lower the freezing point temperature and made the freezing time shorter. It was also found that removing some water was effective to reduce the size of ice crystal and the drip loss in mackerel. After thawing, the pre-dehydrated mackerel showed better microstructure than that frozen without pre-treatment. Furthermore, the sensory tests have been done by a group of panelist for the evaluation on aroma, flavor, and general acceptability of mackerels.

Key words: Pre-Dehydration, Microwave Vacuum Drying, Frozen Storage, Ice Crystal, Cell Damage

1. Introduction

Water management is very important for a long-term preservation of foods. Two methods, drying and freezing, are utilized generally. This study focuses on the freezing but we used new drying technology to dehydrate the foods at a proper moisture-content before the freezing.

Quality loss during the freezing and storing at low temperatures is an important subject not only from commercial point of view but also a public health concern such as the losing nutrient value. One of the reasons of reducing the quality is the formation of large ice crystal since it causes mechanical damages to the tissues. To reduce the formation of ice crystal ultra rapid cooling is necessary in usual processing. However, this method needs large amount of energy. It is also difficult to get such cooling rate for larger materials. In order to develop new method for a good freezing quality removing some water from the materials before freezing has a potential to minimize the formation of harmful ice crystal. That is, the ice-formation probability should be decreased by reducing the water content before the cooling.

Our previous work has shown that smaller ice crystal can be achieved in onion epidermal cells by reducing the moisture content^[1]. It was also found that a reduction of moisture content was also effective to lower the freezing temperature^[1, 2]. The applications of osmotic dehydration, dewatering by soaking in concentrated solution, before freezing has been applied successfully to reduce structural damages and maintaining color on fruits^[3, 4, 5]. The osmotic dehydration of strawberry halves using solution of glycerol, glucose, and sucrose, partially protects tissues from freezing damages, reducing the

exudates significantly [3]. Sormani, et al. [4] found that pre-dehydrated strawberry slices showed much better tissue organization than strawberry frozen without pretreatment. The good color and texture of cut pear also can be maintained upon freezing and thawing by partial dehydration using sucrose solution [5]. However, the utilizing of osmotic solution for dehydration is not desirable for the sensory characteristics especially for the flavor of food products. Then, the objective of this research work is to present a novel freezing method combined with the microwave-vacuum drying. The microwave-vacuum drying enable us to dehydrate the food materials to a desirable moisture content under the room-temperature conditions without causing any drying damages [6].

2. Materials and Methods

2.1 Experiment Design I

In experiment design I we used tuna as the test material. At the initial process three blocks of tuna were dried using microwave-vacuum dryer to remove the water about 9%, 15% and 30%. The initial moisture content of tuna was 2.50 g/g-dry and after drying it became 2.19, 2.0 and 1.45 g/g-dry. The moisture content of material was calculated from

$$\text{moisture content} = \frac{\text{wet weight of sample} - \text{dry weight of sample}}{\text{dry weight of sample}} (\text{g/g} - \text{dry})$$

After being dried the samples were cut into size of 2x2x2 cm³ and frozen in a freezer chamber at temperature of -20°C. The temperature change of the tuna was measured using T-type thermocouple. The thermocouples were inserted in the sample as shown in Fig.1.

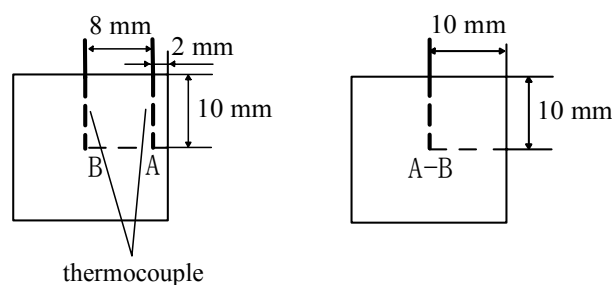


Fig.1 The temperature measurement points in tuna.

2.2 Experiment Design II

Oysters and beheaded mackerels were used as the experimental materials. The materials were purchased in fresh condition from local dealer in Kitakyushu, Japan. Some of the oysters and the mackerels were packed and frozen directly in the freezer after being washed and drained. And, some of them were dehydrated to desirable moisture content using microwave-vacuum dryer prior to the freezing.

2.2.1 Drying method and condition

A microwave-vacuum drying with nitrogen gas supply system was used in this experiment to remove part of water from the samples [6]. During the drying, about 4 L/min of nitrogen gas was flowed through the chamber in order to enhance the evaporation rate and prevent the oxidation. The drying was conducted at pressure about 4kPa and temperature less than 25°C. The temperature was controlled manually. The microwave was switched-off when the temperature of material reached 25°C and it was switched-on when the temperature down to about 22°C. Fig.2 showed the profile of drying temperature

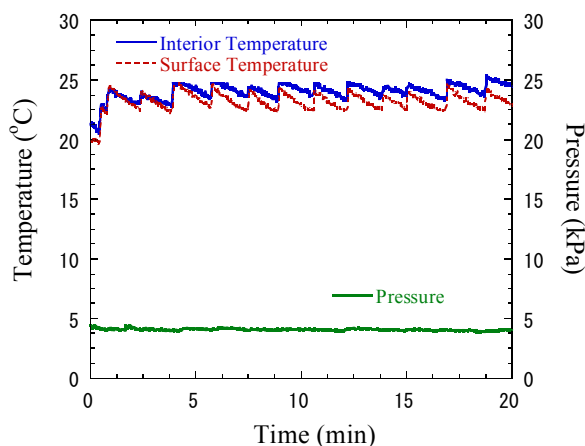


Fig.2. Drying temperature and pressure.

and drying pressure of this experiment. The solid-line showed the interior temperature of material and the dotted-line showed the surface temperature of material.

In this experiment, oysters were dehydrated to 5%, 10% and 15 % weight loss, and the mackerels were dehydrated to 3% and 5% weight loss. After being dried, the moisture content of oyster changed from the initial moisture content of 5.80 g/g-dry to 5.46, 5.12 and 4.78 g/g-dry. The moisture content of mackerels changed from the initial moisture content of 2.33 g/g-dry to 2.23 and 2.16 g/g-dry.

2.2.2 Freezing method and condition

In our experiment the freezing was done using a freezer with digital temperature control system. The freezing chamber was set at temperatures -20°C and -80°C . Three mackerels (300~400 g/fish) were frozen and stored for 7 days for each temperature condition. And about 600 g oysters were frozen in a container of $16 \times 14 \times 6 \text{ cm}^3$ and stored within 14 days for each temperature condition.

The temperature transients of the sample were measured using T-type thermocouple during the freezing. Thermocouple was inserted about 1.5 cm from the body surface for the mackerel and inserted in the middle of the oyster container. By freezing the samples at temperatures -20°C and -80°C , the cooling rates of oysters were $0.18^{\circ}\text{C}/\text{min}$ and $1.5^{\circ}\text{C}/\text{min}$, respectively. With the same freezing conditions, the cooling rates of mackerel were $0.17^{\circ}\text{C}/\text{min}$ and $1.02^{\circ}\text{C}/\text{min}$, respectively.

2.2.3 Ice crystal examination

The morphologies of ice crystal in the mackerel were examined with use of a cryo-microscope. The observation was done on the thin sections ($10\sim 20\mu\text{m}$) of the inner part of materials. The method firstly developed by Tsuruta-Hamidi^[7].

2.2.4 Gravity drip loss (%)

The gravity drip loss was determined by weighing the samples before and after the process. The initial weight was measured before thawing and the final weight was measured after thawing and draining. The samples were drained in a net for 30 minutes. The drip loss was calculated from:

$$\text{drip loss (\%)} = \frac{\text{initial weight} - \text{final weight}}{\text{initial weight}} \times 100\%$$

2.2.5 Protein value in drip (%)

In order to analyze the cell damage due to freezing, we measured the protein within the drip exuded from the oyster. The measuring was done by Japan Food Research Laboratories using Kjeldahl method^[8]. The amount of total protein was determined from the percentage of nitrogen found in the drip by multiplying a conversion factor of 6.25.

2.2.6 Odor evaluation

The odor status of thawed mackerel was assessed by twelve panelists. The panelists were asked to compare the odor of thawed mackerel with the fresh one. The samples were scored on a scale from 0 to 3 (0 = fresh smell, 0.5 = very slight off-odor, 1 = slight off-odor, 1.5 = slight to fishy odor, 2 = significant fishy, 2.5 = strong fishy odor, 3 = totally off). Fresh smell (without off-odor) received the score 0 because undesirable odors are perceived to be absent.

2.2.7 Flavor and acceptability evaluation

The evaluation was also carried out by twelve panelists. They were asked to score the flavor and acceptability of a sample of mackerel. The mackerel was steamed for 10 minutes for this testing. The flavor of samples were scored on a scale from 0 to 3 (0 = no off flavors, 0.5 = very slight off-flavor, 1 = slight off-flavor, 1.5 = slight to distinct, 2 = distinct, 2.5 = distinct to strong, 3 = strong off-flavors)^[9]. The acceptability of the samples was scored from 3 (very acceptable) to 0 (un-acceptable).

2.2.8 Micro-structure examination

A microtome (LEICA CM1510S) was used to prepare tissue for microscopic analysis. After stained with hematoxylin 3G and eosin, cryosections (10 μ m) were observed under a digital microscope (KEYENCE VH-Z 75).

3. Results and Discussion

3.1 Freezing Temperature

The temperature profile of tuna during freezing was shown in Fig.3. It was clearly observed that freezing initiated at lower temperature in the dehydrated samples comparing to the un-dehydrated one. The sample of un-dehydrated tuna, with moisture content of 2.50 g/g-dry, started to freeze at the temperature about -0.5°C , but the super-cooling of the dehydrated sample by 30% weight loss (1.45 g/g-dry) increased to -6.2°C . The results on the nucleation temperature were plotted in Fig.4 as a function of the moisture content. The freezing initiation point decreases with increasing dehydration since the concentration of solution increases in the material.

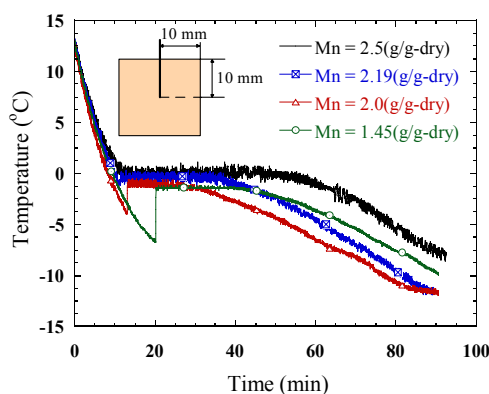


Fig.3 Temperature transients of tuna during freezing (cooling rate, $H=1.5^{\circ}\text{C}/\text{min}$).

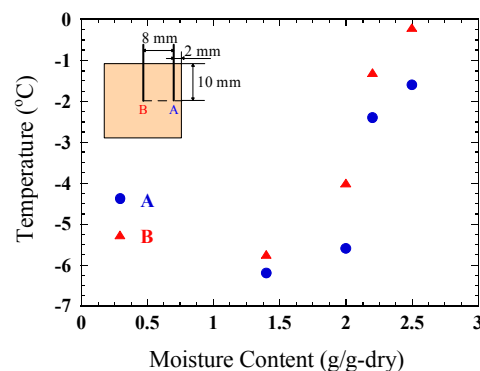


Fig.4 Nucleation temperature of tuna (cooling rate, $H=1.5^{\circ}\text{C}/\text{min}$).

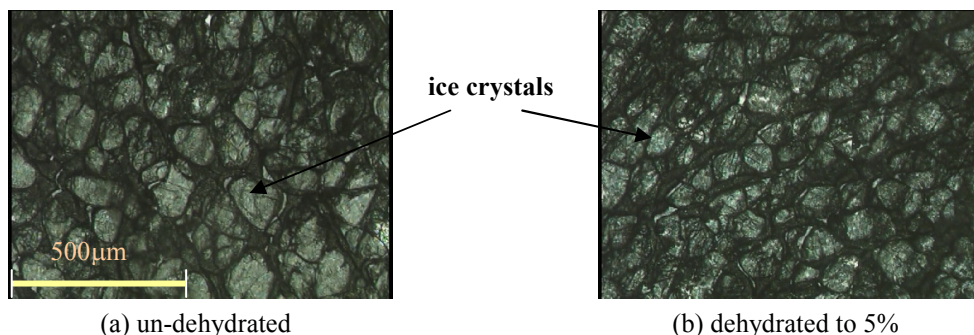


Fig.5 Images of ice crystal in mackerel cooled in -20°C .

In Fig.3 we also see a tendency that the freezing time is shortened by the dehydration, although the sample of $Mn=2.0$ shows the shorter freezing time than that of $Mn=1.45$. Here, the freezing time is usually defined as the time from the onset of nucleation to the end of freezing and it depends on the removal of latent heat for solidification of water [2]. It is understood that the less water content results in the shorter freezing time. The shorter freezing time is effective for the high-quality freezing because the food can pass through the Zone of Maximum Crystal Formation rapidly. Therefore, we consider that the pre-dehydration enables the rapid freezing and has a possibility to control the growth of ice crystal.

3.2 Ice crystals examination

The ice crystal morphologies in mackerels were directly observed by a cryo-microscope. Figure 5 showed the photographs of ice crystals formed in the mackerels which were subjected to the temperature of -20°C . In these images, the ice crystals appear in bright color. Relatively large ice crystals were confirmed in the un-dehydrated mackerel, but the smaller ice crystals appeared in the sample with 5% pre-dehydration. The equivalent diameter of ice crystal was reduced from $123.9\mu\text{m}$ in the un-dehydrated mackerel to $82.45\mu\text{m}$ in the dehydrated to 5%. This means that removing some amount of water was able to reduce the probability of large ice-crystal formation. This result agreed with our previous result [1] that smaller ice crystal can be achieved in the onion epidermal cells by reducing the moisture content.

3.3 Drip and protein loss

The drip loss is a better index to estimate the degree of cell damages. The cells with ruptured membrane release high concentrated solutions after the thawing. On the other

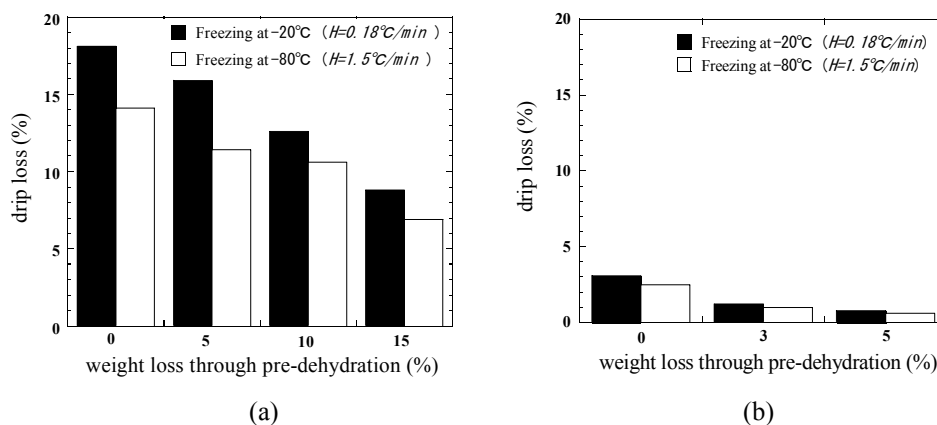


Fig.6 The gravity drip loss of (a) oyster and (b) mackerel after thawing.

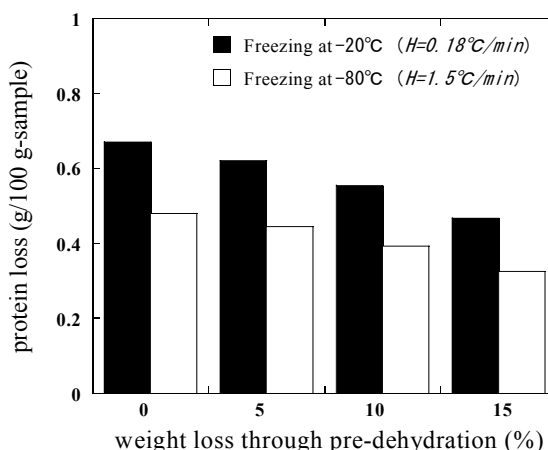


Fig.7 Protein loss of oyster (g/100g-sample) exuded with the drip after thawing.

hand, if the cell damage is small, water can diffuse back to the cells during the thawing process^[10]. Figure 6 shows the drip loss from the oysters and the mackerels frozen at two cooling conditions, which illustrates the drip loss decreases with increasing pre-dehydration. We can understand from the figure that the pre-dehydration is effective for the freezing with better quality.

We also believed the formation of large ice crystals has a close relation to the cell damages. It is generally known that the compression and deformation of cell by the ice crystals result in the mechanical damages of cells^{[11][12]}. Since the formation of large ice crystals can be controlled by removing some amount of water before the freezing (Fig.5b), it is possible to reduce the mechanical damages and the drip loss. The present experiment also indicated that slowly frozen samples (freezing at -20°C) had larger drip compared to the fast frozen samples (freezing at -80°C). This is also reasonable because the slow freezing procedure promotes the formation of large ice crystal^[7, 13].

The examination results on the protein loss from the oyster are also shown in Fig.7. The amount of protein in the drip decreases with the increase of dehydration. It is therefore confirmed that the pre-dehydration can reduce the cell damages.

3.4 Microstructure analysis

Figure 8 shows some photomicrographs of the fresh and the dehydrated mackerels obtained in the microstructure examination. There is no significant difference between the fresh mackerel and the partial dehydrated samples by using microwave vacuum drying. The structures of dehydrated samples were almost similar to the fresh sample.

The microstructures of the thawed mackerels are shown in Figs. 9 and 10. Some ruptured structures are observed in the mackerels frozen without pre-dehydration. Particularly in the un-dehydrated mackerel with slow cooling (Fig 9a) we found many ruptured portion in the fiber muscle structures. However, there is no damage in the pre-dehydrated samples. Compared to the un-dehydrated samples they relatively had better structures. These findings agreed with the changes of drip loss value (Fig. 6). We also see the rapid freezing reduces the damage even for the un-dehydrated materials. This is because rapid freezing is also able to reduce the formation of large ice crystals^[7]. It is conclude that the formation of smaller ice crystal in dehydrated samples is able to reduce the cell damages.

3.5 Flavor, odor and acceptability

Table-1 and -2 showed the averages scores of flavor, odor and acceptability of mackerels frozen at temperature -20°C and -80°C , respectively. The averages scores

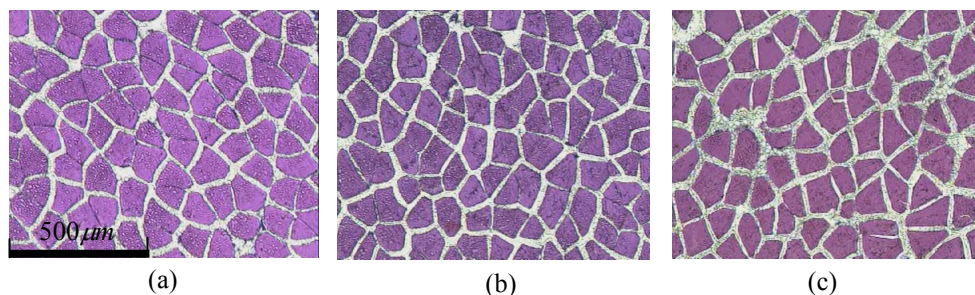


Fig.8. Microstructure of mackerel before freezing: (a) fresh mackerel, (b) dehydrated to 3% weight loss, and (c) dehydrated to 5% weight loss.

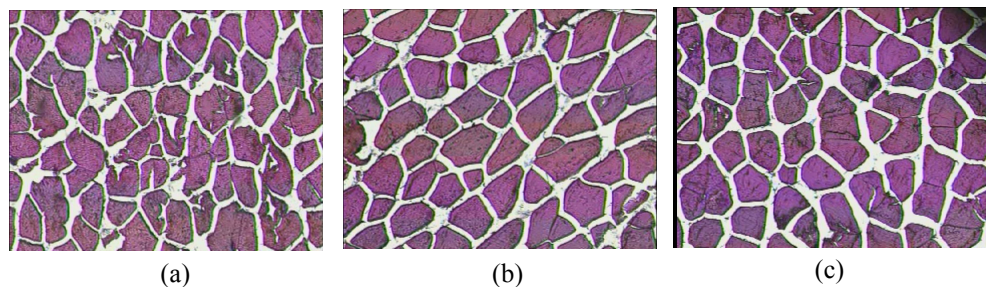


Fig.9. Microstructures of mackerel after thawing (freezing at -20°C). Pretreatment before freezing: (a) un-dehydrated, (b) dehydrated to 3% weight loss, and (c) dehydrated to 5% weight loss.

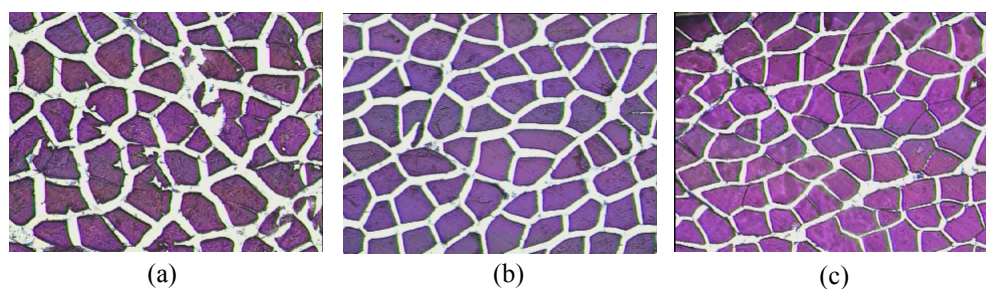


Fig.10. Microstructures of mackerel after thawing (freezing at -80°C). Pretreatment before freezing: (a) un-dehydrated, (b) dehydrated to 3% weight loss, and (c) dehydrated to 5% weight loss.

of the flavor, odor and general acceptability of all samples were relatively good. The results showed that there were only slight changes in flavor, odor and general acceptability between the samples with and without pre-dehydration. It seems, however, that the pre-dehydrated sample had better score in the acceptability than the un-dehydrated one under the slower cooling condition.

Tabel-1 Average score of flavor, odor, and acceptability of mackerel freezing at -20°C .

freezing at -20°C			
Samples	Flavor	Odor	Acceptability
un-dehydrated	0.82	0.73	1.82
dehydrated to 3%	0.45	0.77	2.23
dehydrated to 5%	0.95	0.64	2

Tabel-2 Average score of flavor, aroma, and acceptability of mackerel freezing at -80°C .

freezing at -80°C			
Samples	Flavor	Odor	Acceptability
un-dehydrated	0.68	0.5	2.36
dehydrated to 3%	0.36	0.68	2.36
dehydrated to 5%	0.45	0.5	2.27

4. Conclusion

The experiments on the validity of partial dehydration through microwave vacuum drying have been conducted in order to develop a new freezing method for the better quality of frozen food. Tuna, oyster and mackerel were used as the experimental materials in the experiments. The results showed that the reduction of the water content in tuna could lower the freezing point temperature and shorter the freezing time. The partial dehydration before freezing also gave good results in suppressing the formation of large ice crystal and preventing the structure damages of mackerel due to the freezing. It was also confirmed that this treatment was effective to reduce the drip loss of oyster and mackerel, although there were only slight differences in flavor, odor and general acceptability.

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