Effect of Curing with NaCl Solution on Drying Characteristics of Fish Meat and Its Textural Changes during Drying

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Atka mackerel meats cured with 0.5–2.0 M NaCl containing 20 mM Tris-acetate (pH 7.0) were incubated at 15°C, 30°C and 50°C and in 60% relative humidity for 0–16 hours, and their drying characteristics and textural change during drying at different temperatures were simultaneously investigated. Slow moisture vaporization occurred at the initial drying period and the critical moisture content significantly decreased with an increase in the NaCl content of cured meats. In addition, the reduction of the drying rate in the later drying period was suppressed when 0.5 mol/kg of NaCl were contained in the cured meats. Furthermore, at 15°C and 30°C drying, the increase in the shear force of dried products with the decrease in the moisture content was effectively suppressed by the curing with NaCl. Such changes in the drying characteristics and texture would contribute to depression of the excess hardening and obtaining a long shelf-life of dried products.

Key words: fish meat, drying, NaCl, moisture, texture

The basic purpose of food drying is to create an environment deleterious to the growth of spoilage mechanisms. When dried seafood products are manufactured, foodstuff is often cured with solutions introducing NaCl and other ingredients into meat. The water activity of dried products is effectively decreased by concentration of NaCl in the following drying process, and as a result, dried products can obtain better preservative property.¹⁾ However, if the drying temperature is too high and moisture rapidly decreases, a hard shell is developed on the surface of the materials and moisture is trapped on the inside. This phenomenon is called “case hardening”, which impairs the preservative property of dried products.²⁾ Therefore, it is important to select a drying condition under which moisture vaporization from the surface continues until the moisture content reaches the desired value (required level).

Recently, biochemical changes in fish myofibrillar proteins during drying have been studied for introducing scientific quality control into the production of dried fish products. Raghunath *et al.*³⁾ found a decline in sulfhydryl groups in the dried meat of Japanese threadfin bream. Ito *et al.*⁴⁾ and Tanbo *et al.*⁵⁾ observed production of cross-linked myosin heavy chains in some cured and dried fish meats. They suggested that such structural change in protein would affect the textural formation of dried meat. Nanbu *et al.*^{6,7)} also investigated the osmotic dehydration of fish meat with soaking in NaCl solutions and denaturation of myofibrillar protein during soaking and drying. These findings suggest that NaCl penetrated into fish meat affects structural changes with drying and also its drying characteristics. However, there are few studies focused on the relationship between the texture of dried fish products and moisture diffusivity.

The object of this study is to clarify the role of the curing process in manufacturing dried fish products from the

view of the moisture diffusivity and the structural changes in fish meat. The moisture transportation occurred in cured fish meat and its textural change during drying at different temperatures were simultaneously investigated.

Materials and Methods

Preparation of cured fish meat and its drying

Fresh atka mackerel *Pleurogrammus azonus* (about 800–1,000 g) within one day of postmortem was purchased at a local fish market. All other chemicals (reagent grade) were obtained from Wako Pure Chemical Industries, Ltd. (Osaka, Japan). Meat blocks of ordinary muscle were taken parallel to the muscle fiber at 1 × 1 × 6 cm. Twelve meat blocks obtained from each fish were stuffed into cellulose tubes ($\phi=15.9$ mm) and cured in 2000 ml of 20 mM Tris-acetate (pH 7.0) containing 0.5 M, 1.0 M, 1.5 M and 2.0 M NaCl at 5°C for 13 hours. After removing from the cellulose tubes, cured fish meat thus obtained were incubated at 15°C, 30°C and 50°C and in 60% relative humidity for 0–16 hours in a humidity cabinet (Model PR-1G, Tabai Espec Corp., Tokyo, Japan). The air flow rate was regulated to ≤ 2.5 m/s. Test samples thus obtained were adjusted to 40 mm length by cutting off both ends and were used for texture evaluation. As a control, raw fish meat was dried under the same conditions without curing.

Measurement of moisture content and analysis of drying characteristics

The dried samples were chopped (2–3 g) and incubated at 105°C for 16 hours, and the weight loss was estimated as moisture. When samples were dried at different temperatures, the changes in the drying rates were investigated and drying characteristic curves were drawn for comparing the moisture transportation occurring in each cured meat. The

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drying rate was expressed in a moisture content loss as a function of time. In drying characteristic curves, the moisture content at which an abrupt decrease in drying rate occurred is regarded as the critical moisture content.

Measurement of NaCl concentration

Each 2 g sample was homogenized in 18 ml of cold distilled water and dialyzed against 10 volumes of distilled water at 4°C for 20 hours. The NaCl concentration of the dried meat was determined by measuring the amount of NaCl eluted into the water. The conductivity of the water after dialysis was measured by a conductivity meter.

Mechanical assessment of texture

The modified shear head of the Warner-Bratzler's apparatus was attached to a rheometer (Model RUD-JS, San Kagaku Co., Ltd., Tokyo, Japan), which is eminently suitable for measuring the texture of dried fish meat.⁸⁾ A test sample was attached between the sample stopper and the stainless cutter blade of 0.45 mm thickness, and it was cut by the blade at a speed of 140 mm/min. The shear force (gW) was measured as the highest load value during the sample cutting. There were no significant differences in these parameters among meat blocks from different individuals ($n=6$, $p>0.05$).

Statistical analysis

Tukey's multiple range test⁹⁾ was performed by Minitab 10 system for personal computers (Minitab Inc., State College, PA, USA).

Results and Discussion

Water diffusivity in fish meat cured with different concentrations of NaCl

The moisture content and NaCl concentration of cured meat are listed in Table 1. When fish meats were cured with NaCl solutions, the quantity of NaCl permeated into the samples rose and reached a plateau at four hours for 0.5 M NaCl, ten hours for 1.0 M NaCl, and 12 hours for 1.5 M and 2.0 M NaCl (data not shown). The final NaCl concentration of the cured meat increased with rising NaCl concentration of the curing solutions, and the increments of NaCl corresponded to about 50% of the concentration of the curing solutions. Although fish meat was swelled by curing with 0.5 M NaCl, osmotic dehydration was observed in 1.0–2.0 M NaCl-cured meats, and their moisture content decreased with the increase in the NaCl concentration of the curing solutions. Figure 1 shows changes in moisture content of the cured meats during drying at 15°C, 30°C, and 50°C. The moisture content of the control (raw meat) and 0.5 M NaCl-cured meat more rapidly decreased than that of 1.0–2.0 M NaCl-cured meats during the initial drying period. No drip-loss was observed in any of the samples during drying at 15°C and 30°C. In drying at 50°C, drip exudate was obviously observed in the control and 0.5 M cured meats at the beginning of drying, whereas drip was slightly exuded from 1.0 M–2.0 M cured meat in which osmotic dehydration during curing process was observed. These results indicate that the curing process affects the moisture transportation during the

Fig. 1. Change in moisture content of cured fish meat during drying.

Fish meat blocks cured with 0.5 (Δ), 1.0 ($\bullet$), 1.5 ($\blacktriangle$), and 2.0 ($\blacksquare$) M NaCl solution (pH 7.0) were dried at 15°C, 30°C, and 50°C (60% of relative humidity). As a control, raw meat block ($\circ$) was also dried under the same conditions.

Table 1. Moisture content and NaCl concentration of fish meat cured in NaCl solutions

	Control	NaCl concentration of curing solution (M)			
		0.5	1.0	1.5	2.0
Moisture (g H ₂ O/g dry solid)	3.73 $\pm$ 0.16	4.04 $\pm$ 0.12	3.16 $\pm$ 0.11	2.90 $\pm$ 0.08	2.77 $\pm$ 0.05
NaCl (mole/Kg)	0.11 $\pm$ 0.01	0.35 $\pm$ 0.04	0.62 $\pm$ 0.08	0.86 $\pm$ 0.06	1.13 $\pm$ 0.06

Data was mean $\pm$ S.D. of 3 experiments.

Fig. 2. Drying characteristic curve of cured fish meat. Symbols are the same as in Fig. 1.

Fig. 3. Effect of curing critical moisture content of cured fish meat. Control: raw meat without curing.

following drying process.

The drying characteristic curves of the cured meat depicted from the data of Fig. 1 are shown in Fig. 2. The constant-rate drying period and the falling-rate drying period were observed in all the samples. The constant drying rates of the cured fish meats significantly decreased by curing with higher concentrations of NaCl solutions at all temperatures. However, as shown in Fig. 1, the moisture contents of 1.0–2.0 M NaCl-cured meats were always lower than that of 0.5 M NaCl-cured meat. This occurred because the constant-rate drying periods were relatively short during the drying process and the initial moisture content of the cured meats was lowered by the osmotic dehydration which occurred in the curing process. Furthermore, in the falling-rate drying period at 15°C and 30°C drying, the reduction of the drying rate of 1.0–2.0 M NaCl-cured meats took place at slower rates than that of the control and 0.5 M NaCl-cured meat. As a result, the drying rates

changed to be higher than those of the control and the 0.5 M NaCl-cured meat, when their moisture contents reached 2.0 g H₂O/g dry solid. Although this effect was not observed in 50°C drying, this is because much drip exudation occurred in the control and the 0.5 M NaCl-cured meat during drying. These results indicate that an effective moisture vaporization from the surface of fish meats was continued by curing with NaCl. The results of Fig. 3, which show that significant decrease in the critical moisture content was caused by curing with NaCl, also support this interpretation.

Effect of NaCl on textural change in cured meat during drying

As presented in Fig. 4, changes in the shear force of cured meats were greatly dependent on the drying temperature. At the beginning of drying at 50°C, the shear force of all the samples decreased with the exudate of the drip. In particular, the control and 0.5 M NaCl-cured meat, in which much drip exudate was observed, became porous dried products as the drying progressed. As a result, their shear force was lower than that of 1.0–2.0 M cured meats during heating process. This result indicates an undesirable textural change of cured meat occurred at high temperature-drying would be suppressed by curing with high concentration of NaCl.

On the other hand, in drying at 15°C and 30°C, the shear force of all samples increased, although the increasing rate at 30°C diminished when the moisture content reached below 1.8 g H₂O/g dry solid. It was also confirmed that there was no difference in the shear force changes among the five samples containing different amounts of NaCl ($p > 0.05$). However, the moisture contents of the dried meats obviously differ from one another when compared at the same drying period, and it is apparent that the moisture content is an affecting factor in developing the texture of dried meat. Thus, we investigated the relationship between the shear force and the moisture

Fig. 4. Change in shear force of cured fish meat during drying. Symbols are the same as in Fig. 1. Error bar is a standard deviation ($n=6$).

Fig. 5. Relation between shear force and moisture content of dried fish meat.

Symbols are the same as in Fig. 1. Open and closed symbols mean the low and high-salted groups, respectively.

content of the cured meats at 15°C and 30°C. As shown in Fig. 5, there was no difference in the change in the shear force dependent on the moisture decrease between the control and 0.5 M NaCl-cured meat (named the low-salted group), or among 1.0–2.0 M NaCl-cured meats (named the high-salted group) at all temperatures ($p>0.01$). However, a significant difference in the relationship between the shear force and the moisture content was observed between two such groups of fish meats ($p<0.01$). The shear force of the high-salted group was always lower than that of the low-salted group during drying at 15°C ($p<0.01$). For example, the shear force of the high-salted group was lower than that of the low-salted group by 1.5 times at 1.5 g H₂O/g dry solid of moisture content, and by 2.2 times at 2.5 g H₂O/g dry solid of moisture content. This result indicates that curing with NaCl effectively depresses the hardening of dried fish meat products. Although the same trend was also observed in 30°C drying, which diminished with an increase in drying temperature. Therefore, it is apparent that drying at lower temperature is desirable for hindering an excess hardening of dried products.

The textural difference between the two sample groups (shown in Fig. 5) would reflect the development of a hard shell on the surface of the dried products. In fact, when

the low-salted group was dried in 15°C and 30°C, a hard shell was rapidly developed on the outside of the samples, and an apparent moisture gradient between the deeper parts and the surface was observed. Therefore, suppression of the hard shell would contribute to the effective moisture vaporization observed in the high-salted group.

Thus far the role of the curing process in manufacturing dried fish products has been discussed as reducing the water activity of dried products by the addition of salt. In this study, it was further shown that the curing process would help to manufacture dried products with a long shelf-life by the suppression of “case hardening”, and depress an excess hardening of dried fish meat products. These findings should be useful in understanding conventional manufacturing technology, preparing better quality products, and designing an effective process line.

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