INTRODUCTION

The basic purpose of food drying is to create a deleterious environment to the growth of microorganisms by decreasing the water activity of products. Various kinds of dried seafood are manufactured from marine bioreources such as fish, shellfish, and molluscs in many countries. Efficient methods of moisture removal from materials have been developed in the manufacturing of dried seafood, and modeling systems of fish-drying kinetics have been proposed for estimating optimum drying conditions.1,2 The treatment of materials is also important for manufacturing high-quality dried seafoods. Curing processes often use a high concentration of salts and/or sugars to achieve better preservative properties in dried seafood because lower water activity is effectively obtained by concentrating ingredients introduced into the materials in the subsequent drying process.1 Sugars also affect the moisture diffusivity in food-drying processes, and sorbitol, a non-reducing sugar with moderate sweetness, is a popular ingredient for regulating the water activity of dried foods.3 Nanbu et al.5,6 have reported that denaturation of fish myofibrillar protein during drying and a decrease in water-retention ability of dried fish meat are effectively suppressed by sorbitol. On the other hand, biochemical changes in myofibrillar proteins during curing and drying have been studied with the aim of introducing scientific quality control into the manufacture of dried fish products. Ito et al.7 and Tanbo et al.8 observed the production of cross-linked myosin heavy chains in NaCl-cured fish meats during drying, and they suggested that such a structural change in protein would affect the textural formation of dried meat. Funatsu et al.9 also reported that sorbitol changed the rheological characteristics of dried walleye pollack meat, including a high concentration of NaCl. These findings indicate that the ingredients introduced into materials in the curing process affect not only the shelf-life but also the texture of dried seafoods. We have already reported that the curing process would help to manufacture dried products with long shelf-life by suppression of ‘case hardening’, and eliminate the excess hardening of dried fish products.10 However, the relation between moisture transportation in the manufacture of dried seafoods with the sorbitol-curing process and the textural change of dried products has not been fully investigated. Therefore, the object of this study is to clarify the role of sorbitol in the process of dried seafood products. The effects of sorbitol on the moisture removal from fish and

Original Article

Effect of sorbitol on moisture transportation and textural change of fish and squid meats during curing and drying processes

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SUMMARY: Atka mackerel (Am) and Japanese common squid (Sq) meats were cured in 0.5–1.5 M sorbitol solutions (pH 7.0) and dried at 30°C (relative humidity, 60%), and the effect of sorbitol on the moisture transportation and textural change during the curing and drying processes was investigated. With an increase in sorbitol permeated through samples, the moisture contents decreased by 52% (Am) and 42% (Sq) by curing in 1.5 M sorbitol solution. When the cured meats were dried, slow moisture vaporization occurred at the initial drying period, and the critical moisture content significantly decreased with an increase in the sorbitol content of the cured meats. Further, the hardening of the dried products was effectively suppressed by sorbitol curing. These effects of sorbitol would contribute to the reduction of drying time and particularly the elimination of the excess hardening of dried fish products.

KEY WORDS: dehydration, drying, fish, moisture, muscle, sorbitol, squid, texture.
squad meats during the curing and drying processes were examined along with the relationship between the texture of dried fish products and its moisture transportation.

MATERIALS AND METHODS

Material

Fresh atka mackerel *Pleurogrammus azonus* (Am: mean weight, 940 ± 10 g) within 1 day of post-mortem and quick-frozen Japanese common squid *Todarodes pacificus* (Sq: mean weight, 276 ± 68 g) were obtained at a local fish market. Cellulose tubing and membrane (for dialysis) were purchased from Sankou Jun-yaku Co. Ltd (Tokyo, Japan). Sorbitol was provided from Towa Chemical Industry Co. Ltd (Tokyo, Japan), and all other chemicals (reagent grade) were obtained from Wako Pure Chemical Industries Ltd (Osaka, Japan).

Preparation of sample pieces

A meat block of Am (ordinary muscle) was taken parallel to the muscle fiber at 1 × 1 × 6 cm and stuffed into a cellulose tube (15.9 mm in diameter). Eight to 10 meat blocks were obtained from one individual. A Sq meat piece was sampled from the middle of skinned mantle, whose thickness was 4.3 × 0.7 mm (n = 40). The test piece (1.5 cm wide) was cut perpendicularly to the body axis (6 cm in length) and wrapped with a cellulose membrane. Twelve sample pieces were obtained from one individual.

Preparation of cured fish meat and its drying

Twelve meat blocks were cured in 2000 mL of 20 mM Tris-acetate (pH 7.0) containing 0.5–2.0 M sorbitol or 0.5–2.0 M NaCl at 4°C for 18 h. After removing the cellulose tubes or membranes, the cured sample pieces thus obtained were dried at 30°C and 60% relative humidity for 0–16 h in a humidity cabinet (Model PR-1G; Tabai Espec Corp., Tokyo, Japan). The airflow rate was regulated to about 2.5 m/s. Dried sample pieces were adjusted to 40 mm length by cutting off both ends and then used for texture evaluation. As a control, raw Am and Sq sample pieces were dried under the same conditions without curing.

Measurement of moisture content and analysis of drying characteristics

The dried sample pieces were chopped (2–3 g) and incubated at 105°C for 16 h, and the weight loss was estimated as moisture. Changes in the moisture content of sample pieces during drying were measured, and the drying characteristic curves were drawn for comparing moisture transportation. The drying rate was expressed in moisture content loss as a function of time. In the drying characteristic curves, the moisture content at which an abrupt decrease in drying rate occurred was regarded as the critical moisture content.

Measurement of sorbitol concentration

Each cured sample piece was homogenized with cold distilled water and centrifuged at 10,000 g for 30 min, and 7.5% trichloroacetic acid (final concentration) was added to the supernatant. The mixture was kept at room temperature for 30 min and then centrifuged at 3000 g for 30 min. After adjusting the pH to 7.0 with 1.0 M KOH, the supernatant was used for sorbitol analysis with an enzyme analysis kit (D-Sorbitol/Xylitol Analysis Kit; Boehringer Mannheim, Mannheim, Germany).

Measurement of NaCl concentration

The NaCl concentration of the sample meat was determined by measuring conductivity of the water extract of cured meat as presented in the previous report.10

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.11 A sample piece was attached between the sample stopper and the stainless cutter blade of 0.45 mm thickness and then cut longitudinally in a slab form 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 specimens of Am and Sq (n = 6, P > 0.05).

Statistical analysis

Tukey’s multiple range test12 was performed by Minitab 10 system for personal computers (Minitab Inc., State Collage, PA, USA).
RESULTS AND DISCUSSION

Amount of sorbitol permeated into fish and squid meats during the curing process

Table 1 shows sorbitol and NaCl contents of Am and Sq meats cured in various solutions. The sorbitol contents increased with rising sorbitol concentration of the curing solution. The increments of sorbitol (Y) corresponded to about 40% of the concentrations in cured solution (X), and the relationships were $Y = 0.418X - 0.01$ for Am ($r = 0.998$) and $Y = 0.442X + 0.026$ for Sq ($r = 0.995$). Compared with sorbitol, NaCl was easily introduced into the materials, and the increment of NaCl in Am and Sq cured meats corresponded to 60% and 50% of the concentration of the curing solution, respectively. Nanbu et al.\(^6\) reported that sorbitol and NaCl permeated independently to walleye pollack meat at the curing process with solutions containing sorbitol and NaCl, which agrees with the transportation of ingredients observed in this work. That is, the coexistence of 0.5–2.0 M NaCl has no effect on the sorbitol permeation in Am and Sq meats, although the NaCl permeation was slightly diminished in the presence of sorbitol. These findings suggest that the final sorbitol concentration in cured fish meats could be estimated for a more complicated curing system.

Moisture transportation from fish and squid meats

Figure 1 shows the moisture contents of the cured meats. Osmotic dehydration of Am and Sq meats was observed in sorbitol curing. The moisture contents of the raw meats were 3.75 g H₂O/g dry solid in Am and 3.11 g H₂O/g dry solid in Sq, and they decreased with an increase in the sorbitol concentration of the curing solution. As a result, their moisture contents were diminished to 1.81 g H₂O/g dry solid (Am) and 1.79 g H₂O/g dry solid (Sq) by curing in 1.5 M sorbitol. The dehydrating effect was more highly observed in sorbitol curing than NaCl curing. In fact, Sq meats swelled by curing in
Drying or sorbitol-cured fish meat

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0.5 M and 1.0 NaCl solutions. However, when Sq meat was cured in 0.5 M sorbitol solution containing 1.0 M NaCl, the moisture content of the cured meat decreased to 1.80 g H₂O/g dry solid, and the dehydrating effect was almost the same as the effect of 1.0 M sorbitol curing. It is known that the water-holding capacity of myofibrillar proteins increases in a medium containing more than 0.1 M NaCl. However, the osmotic dehydration was obviously enhanced in the presence of NaCl and it would have reflected the behavior of the greater part of free water in the fish meats. Therefore, sorbitol curing together with NaCl would be a useful method to lower the sorbitol content of dehydrated meats.

Changes in the moisture content of the cured meats during drying were investigated, and their drying characteristic curves are shown in Fig. 2. Although a constant-rate drying period and a falling-rate drying period were observed in the drying characteristic curves of all samples, sorbitol curing changed the drying characteristics of both drying materials. The constant drying rates of the Am and Sq meats were significantly lowered with rising sorbitol concentration of the curing solution. However, as presented in Fig. 3, the critical moisture contents of the Am and Sq meats diminished by curing with higher concentrations of sorbitol solutions. These results indicate that effective moisture vaporization from the surface of the dried meats was achieved by curing with sorbitol.

The amounts of moisture removed by osmotic dehydration and the moisture vaporization from sample meats were calculated to understand the effect of sorbitol on the moisture transportation. As shown in Fig. 4, the amount of moisture removed during the curing process

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**Fig. 2** Drying characteristic curve of cured fish and squid meats. (a) Atka mackerel and (b) Japanese common squid meat blocks cured in 0.5 M (○), 1.0 M (△), and 1.5 M (□) sorbitol solution (pH 7.0) were dried at 30°C and 60% of relative humidity. As a control, a raw meat block without curing (●) was also dried under the same conditions.

**Fig. 3** Effect of sorbitol curing on critical moisture content of fish and squid meats.

**Fig. 4** Comparison of moisture transportation during curing and drying processes. The amount of moisture removed from samples at each manufacturing step was expressed as percentage of moisture content of raw meat. (■) Moisture dehydrated in curing process; (□) moisture vaporized in constant-drying rate period; (△) moisture vaporized in falling-drying rate period; and (○) equilibrium moisture content.
increased with an increase in the sorbitol concentration of the curing solutions, and 52% (Am) and 42% (Sq) of total moisture were removed by the osmotic dehydration in 1.5 M sorbitol. Furthermore, marked changes in the moisture vaporization at the drying process occurred in Am and Sq meats. The amount of moisture vaporized at the falling-rate drying period was significantly reduced by sorbitol curing. That is, the amount of moisture vaporized at the falling-rate drying period was 72% (Am) and 74% (Sq) of the total in the raw meats, and 24% (Am) and 37% (Sq) in 1.5 M sorbitol-cured meats. In contrast, no such great change was observed in the moisture vaporization during the constant-rate drying period, and the amount of vaporized moisture was increased by 0.5 M sorbitol curing. These changes in the drying characteristics and the decrease in the amount of moisture vaporized at drying process caused shortening of the drying time. For example, the drying time in which the moisture contents of Am and Sq meats became 1.0 g H$_2$O/g dry solid was diminished to 50% by 1.5 M sorbitol curing. Thus, sorbitol curing would contribute to shortening the drying process of seafood manufacturing.

**Effect of sorbitol on textural change in cured meats during drying**

Figure 5 shows changes in the shear force of the sorbitol- and NaCl-cured meats during drying. Raw meats were also examined as a control. The shear force of the raw meats and all of the NaCl-cured meats increased as the drying proceeded, and there was no difference in the textural change between NaCl-cured meats and raw meats (P<0.01). For example, the shear force of Am and Sq meats cured in 1.5 M NaCl solution increased by 16 h of drying from 380 to 1490 gw and from 1320 to 1940 gw, respectively. On the contrary, such marked increases in the shear force did not occur in either of the sorbitol-cured meats. Namely, the shear force of Am meat cured in 1.5 M sorbitol solution slightly increased from 620 to 894 gw for 16 h. Furthermore, no textural change was observed in Sq meats cured in 0.5–1.5 M sorbitol.

In Fig. 5, there was no difference in the shear force change among three kinds of sorbitol-cured meats (P>0.05) in either species, when compared at the same drying time. Thus, the relationship between the shear force and the moisture content of the dried meats was investigated and presented in Fig. 6 (the data of the raw meat and 1.5 M NaCl-cured meat were considered as controls). In Am meats, the relationship between the shear force and the moisture content of the sorbitol-cured meats was obviously different from that of raw meat and 1.5 M NaCl-cured meat (P<0.01). The shear force of the sorbitol-cured meats was always lower than that of the raw meat and the 1.5 M NaCl-cured meat at the same moisture content. For example, the shear force of 1.5 M sorbitol-cured meat was lower than that of raw meat by 2.1 times at 1.0 g H$_2$O/g dry solid of moisture content, and by 1.8 times at 1.8 g H$_2$O/g dry solid of moisture content. The same textural change resulting from sorbitol curing was also observed in dried Sq meats, and the shear force was 2.1 times lower than that of the raw and NaCl-cured meats at 1.0 g H$_2$O/g dry solid of moisture content. These results indicate that an increase in the shear force with a lowering in the moisture content of the dried meats was effectively eliminated by sorbitol curing. In the previous paper, we reported that NaCl curing prevented the development of 'case hardening' in dried Am meat, and the same effect was confirmed in the sorbitol curing in this work. Furthermore, it is apparent that sorbitol has a strong effect on
suppressing the hardening of dried fish and squid meat products. Thus far, the role of the curing process in manufacturing dried seafood has been that of reducing the water activity of dried products by concentration of ingredients at drying process. Further, it has been shown that the curing process would help to manufacture dried products with a long shelf-life by suppressing the excess hardening of dried fish and squid meat products. In addition, the importance of osmotic dehydration was confirmed in the shortening of the drying process. These findings would be useful for estimating the optimum process conditions in dried seafood.

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REFERENCES