Permeation of sodium chloride into fish meat and its effect on moisture content as a function of the osmotic pressure of the soaking solution

TOORU OOIZUMI,* MAYUMI KAWASE AND YOSHIKI AKAHANE

Department of Marine Bioscience, Faculty of Biotechnology, Fukui Prefectural University, Obama, Fukui 917-0003, Japan

ABSTRACT: Permeability of sodium chloride (NaCl) into fish meat strips caused by soaking was compared with that of sorbitol as a function of osmotic pressure of the soaking solution. Increase in the osmotic pressure of the soaking solution similarly promoted the permeation of both compounds. However, the increasing rate of the permeation of sorbitol gradually decreased with rising osmotic pressure, while that of NaCl was constant under the osmotic pressure range tested. Higher dispersing ability of NaCl in meat strips was thought to promote further permeation of NaCl. In contrast, soaking in NaCl solution with a lower concentration markedly increased the moisture content of the meat strips. Further increase in the osmotic pressure of NaCl in the soaking solution caused the osmotic dehydration similar to sorbitol. Dewatering effect of NaCl was considerably lower than that of sorbitol at the same osmotic pressure. Combined use of NaCl and sorbitol in the soaking solution gave no further promoting action on the permeation of each compound, nor on their dewatering effects. These results suggested that the osmotic dehydration was competitive with the increase in the water-holding capacity of myofibrillar proteins caused by the permeation of NaCl.

KEY WORDS: dewatering effect, osmotic pressure, permeability, soaking, sodium chloride, sorbitol.

INTRODUCTION

Sodium chloride (NaCl) is widely used as an essential additive to process seafoods. It is useful not only for conferring a salty taste but also for protecting seafood from bacterial spoilage by controlling its water activity. Furthermore, NaCl is known to contribute to an increase in water-holding capacity of fish meat as well as to the formation of the elastic texture of kamaboko gel through solubilization of myofibrillar proteins. With the exception of making surimi based-products from minced meat, soaking is a general and conventional method to increase the NaCl content of fish fillets. It is well known that the NaCl content in the fillet exerts significant effects on the quality of processed seafoods. This is related to the fact that biochemical changes in myofibrillar proteins of fish meat by processing and subsequent storage are dependent on the NaCl content in the meat. For example, Ito et al.1–3 and Tambo et al.4,5 suggested that the cross-linking reaction of myosin heavy chains of fish meat caused by salting and drying was NaCl dependent and was involved in developing the texture of salted-dried products. Furthermore, Iseya et al.6 elucidated that the NaCl content in cured fish meat affected its drying characteristics and textural change by drying. Therefore, the regulation of the permeation of NaCl into fish fillet is indispensable for the quality control of seafoods. However, so far, the quantitative aspects of the permeability of NaCl into fish fillets has not been established, because the size and freshness of the fillet as well as the concentration of the soaking solution affect the permeation of NaCl into the fish fillet in a complex manner.

We have investigated the permeability of several sugars into fish meat strips with a uniform size as a function of the osmotic pressure of the soaking solution and have reported that lowering the molecular weight of sugars caused an increase in the permeability and a decrease in the dewatering effect.7,8 The objective of the present study was to elucidate the relation between the permeation or the dewatering caused by soaking and the osmotic
pressure of NaCl in comparison with that of sorbitol. Furthermore, the effects of the combined use of NaCl and sorbitol in the soaking solution on their permeability and dewatering effects were also investigated.

MATERIALS AND METHODS

Soaking of fish meat strips

Fish meat strips with a uniform size and shape (1×1×6 cm) were prepared from the dorsal muscle tissue of small yellowtail, which was caught in the Sea of Japan and was ice-stored within a day before the soaking test. Various concentrations (0.25–2.0 M) of NaCl, sorbitol and a mixture of the two were used as soaking solutions. The mixture contained 1.5 M NaCl and 0.5, 1.0 or 2.0 M sorbitol as well as 1.0 M sorbitol and 0.25, 0.75 or 1.5 M NaCl. The fish meat strips were soaked in double the weight of the soaking solutions according to the previous reports. At appropriate intervals, the meat strips were taken out of the soaking solution and the surface of the soaked meat strips was wiped with filter paper to remove the fluid. After mincing and mixing uniformly, the levels of NaCl, sorbitol or moisture of the meat strips were determined. The soaking test was repeated at least twice using different origins of yellowtail and the levels of these components were averaged. Irrespective of the difference in the type and the concentration of the soaking solution, permeation of both compounds reached a maximum and the moisture content remained constant after soaking for 45 h.

To compare the dispersion ability of NaCl with that of sorbitol, the meat strips, which were soaked in 1.5 M NaCl or 2.0 M sorbitol for 48 h, were cut into four layers from the surface toward the center and the content of NaCl or sorbitol in each layer was determined.

Sorbitol used in this study was food additive grade (Towa Chemical Industry, Tokyo, Japan) and other chemicals were reagent grade (Nacalai Tesque Inc., Kyoto, Japan).

Measurement of the content of NaCl, sorbitol and moisture

Sorbitol was extracted from the samples according to the method of Yasui et al. with a slight modification and was determined with high-performance liquid chromatography (HPLC) using TSK Gel Amide 80 packed column (TOSOH Co. Ltd, Tokyo, Japan). NaCl was determined by thiocyanometric titration after heating the samples with nitric acid. Moisture content in the soaked meat strips was estimated by measuring the weight loss after drying at 110°C for 20 h.

Calculation of osmotic pressure

Osmotic pressure of sorbitol and NaCl in the soaking solution was calculated according to the equation presented by Ogawa. In general, osmotic pressure is estimated as a function of molality of the solute. In Ogawa's equation, it is corrected by considering the specific gravity of the solution as well as the dissociation degree of the solute.

RESULTS AND DISCUSSION

Effect of osmotic pressure on permeation of NaCl

The relationship between the maximum content of each compound in the meat strips and the osmotic pressure of the soaking solutions is shown in Fig. 1. The maximum NaCl content in the meat strips linearly increased in proportion to the osmotic pressure.
pressure of the soaking solution. In contrast, the maximum sorbitol content increased linearly with the osmotic pressure of the soaking solution under the lower pressure range (below 30 atm) but the increasing rate gradually decreased under the higher pressure range (over 30 atm). Dependency of the maximum sorbitol content in the meat strips on osmotic pressure was in accordance with that obtained by using horse mackerel meat strips as reported previously. Although the maximum contents of both compounds were nearly equal to each other at the same osmotic pressure below 30 atm, the maximum NaCl content became considerably higher than that of sorbitol in the osmotic pressure range over 30 atm. In the previous papers, we defined the permeation rate by estimating the maximum sugar content when soaked in the solution with 1 atm of osmotic pressure because there was a linear relation between the maximum content and the osmotic pressure. Moreover, we demonstrated that the permeation rate of sugars increased with lowering of their molecular weights. However, despite the lower molecular weight of NaCl, the permeation rate of NaCl was almost the same as that of sorbitol under the lower osmotic range. The cause is currently unclear. A possible reason may be that the molecular weight dependency of the permeation rate of ionic compounds like NaCl is different from that of sugars, which are non-ionic compounds. Thus, further study is necessary on the permeability of other ionic compounds into fish meat.

Dispersion of NaCl in the meat strips

Previously, we also reported that the content of sugars in the external part of the soaked meat strips was considerably higher than in the internal part, suggesting the sluggish dispersion of sugars in the meat strips. Therefore, we attempted to investigate the dispersing ability of NaCl in the meat strips and to compare it with that of sorbitol. The contents of both compounds in the different parts of the meat strips were plotted against the distance from the surface (Fig. 2). The contents of both compounds decreased with the distance from the surface. The NaCl content in the most internal part was approximately 60% of that in the most external part, whereas the relative content of sorbitol in the most internal layer was approximately 25%. These results suggest that the dispersing ability of NaCl in the meat strips is significantly higher than that of sorbitol. Presumably, rapid migration of NaCl from the surface toward the center of the meat strips would promote the additional permeation by further soaking. Consequently, a constant permeation rate would be kept even in the higher osmotic range (Fig. 1).

Effect of osmotic pressure exerted by NaCl on moisture content of soaked meat strips

The loss of moisture content, which was defined as the difference in the moisture content of the meat strips before and after soaking for 45 h, was plotted against the osmotic pressure of either NaCl or sorbitol in the soaking solution. In Fig. 3, the negative value of the loss of moisture content implies an increase in the moisture content by soaking. Soaking of the meat strips in both solutions with lower osmotic pressure resulted in a moisture increase. Rising of the osmotic pressure of both soaking solutions linearly increased the loss of moisture content. The loss of moisture content caused by soaking in NaCl solution turned to a positive value at approximately 50 atm of osmotic pressure, while only 15 atm of osmotic pressure of sorbitol solution was sufficient to cause actual moisture decrease. At the same osmotic pressure, the loss of moisture content induced by soaking of NaCl solution was considerably smaller than that of the sorbitol solution. The dependency of moisture loss caused by soaking in sorbitol solution on osmotic pressure was almost the same as what was previously reported. The slope of the loss of moisture content versus the osmotic pressure plot gave the dewatering rate, which was conveniently defined
Permeability of NaCl into fish meat

FISHERIES SCIENCE 833

as the loss of moisture content induced by 1 atm of osmotic pressure. Thus, the dewatering rate of NaCl was somewhat lower than that of sorbitol.

Presumably, the water-holding capacity of fish meat would increase with the solubilization of myofibrillar proteins introduced by the permeation of NaCl, resulting in a significant increase in the moisture of the meat strips when soaked in a lower concentration NaCl solution. Konno et al.\textsuperscript{12} reported that sugar compounds also increased the amount of solubilized myofibrillar proteins in the presence of a lower concentration of neutral salt. Accordingly, a slight increase in moisture content of the meat strips soaked in the lower concentration of sorbitol might be explained by an increase in water-holding capacity of partially solubilized myofibrillar proteins. It was therefore suggested that the osmotic dehydration by NaCl solution was competitive with the increase in the water-holding capacity of myofibrillar proteins induced by the permeation of NaCl. In other words, higher osmotic pressure is required to reduce the moisture content of the NaCl-soaked meat strips, in which water-holding capacity of myofibrillar proteins increased.

In addition, we noticed that distribution of moisture in the meat strips soaked in NaCl solution was quite different from that in sorbitol solution. The details are shown another paper published in this issue of the Journal.

Effect of coexistence of NaCl and sorbitol in soaking solution on their permeation and the loss of moisture content

Previously, Nanbu \textit{et al.}\textsuperscript{13-16} reported that the combined use of sorbitol with NaCl was effective in controlling not only the denaturation rate of myofibrillar proteins but also the moisture content of fish meat during the soaking and drying process. Subsequently, Funatsu \textit{et al.}\textsuperscript{17} confirmed that the control of the denaturation rate of myofibrillar proteins by sorbitol during the soaking and drying process affected the rheological properties of salted-dried products. Furthermore, Iseya \textit{et al.}\textsuperscript{18} and Kubo and Saeki\textsuperscript{19} reported the beneficial effect of sorbitol on the moisture transportation and textural control of dried seafoods made from fish and squid. In order to regulate the content of NaCl and sorbitol, the effect of the combined use of both compounds on the permeation of each compound and the moisture change must be understood. Therefore, we examined the permeation of both compounds and the dewatering when the meat strips were soaked in the mixture of NaCl and sorbitol. The maximum contents of NaCl and sorbitol of the meat strips were plotted against the total osmotic pressure of both compounds in the soaking solution (Fig. 4). Total osmotic pressure is the sum of the osmotic pressure given by NaCl and sorbitol in the solution. Assuming that the same relation between the permeation of NaCl and the osmotic pressure was given even in the presence of 1.0 M sorbitol, the theoretical relation between the maximum NaCl content and the osmotic pressure is shown as a broken line (Fig. 4a). The maximum NaCl contents measured were well in accordance with the values on the broken line. Similarly, the maximum sorbitol contents obtained by soaking in the mixture of NaCl and sorbitol also agreed with the values on the theoretical line, on the assumption that the same relation between the permeation of sorbitol and the osmotic pressure occurred in the presence of NaCl (Fig. 4b). These results strongly suggest that the combined use of NaCl and sorbitol in the soaking solution gave no further promoting effect on the permeation of each compound.

Subsequently, we investigated the cooperative dewatering effects of NaCl and sorbitol from the meat strips caused by soaking. Figure 5 shows the
relationship between the loss of moisture content and the total osmotic pressure of the soaking solution. When the meat strips were soaked in the 1.5 M NaCl solution containing 0.5, 1.0 or 2.0 M sorbitol, the loss of moisture markedly increased with the increase in the osmotic pressure induced upon addition of sorbitol. The dewatering rate was slightly lower than that obtained by using the soaking solution containing sorbitol alone. In contrast, when the meat strips were soaked in 1.0 M sorbitol solution containing 0.25, 0.75 or 1.5 M NaCl, the slight increase in the loss of moisture content was observed with the increase in the osmotic pressure upon addition of sorbitol. The dewatering rate of NaCl in the presence of sorbitol was considerably lower than that in the absence of sorbitol. This phenomenon would be explained by the increase in the water-holding capacity of solubilized myofibrillar proteins caused by permeation of NaCl into the meat strips. Probably, the increase in the concentration of sorbitol in the mixture merely caused osmotic dehydration, whereas the increase in the concentration of NaCl in the mixture played the dual roles: osmotic dehydration and the increase in the water-holding capacity of fish meat through the solubilization of myofibrillar proteins.

In the present study, we characterized the permeability and the dewatering effect of NaCl by soaking in comparison with those of sorbitol in terms of the osmotic pressure of the soaking solution. Thus, the quantitative aspect for the perme-
ability and the dewatering effect as a function of the osmotic pressure was thought to be effective to compare those of various food additives, hereby giving a great advantage in the quality control of processed seafoods by using the soaking method.

ACKNOWLEDGMENTS

We are sincerely grateful to Dr Ken-ichi Arai (National Surimi Manufacturers Association, Japan) for his numerous suggestions and critical reading of the manuscript. We also thank Professor Youling L Xiong (University of Kentucky, USA) for his suggestions to improve the English expression of the manuscript. A part of this study was supported by a grant from The Salt Science Research Foundation, Japan. Sorbitol used in this study was generously provided by Towa Chemical Industry Co. Ltd, Japan.

REFERENCES