



Distribution Coefficients of Sodium Chloride on Konjac and Mackerel in Prepackaged Food

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The objective of this study was to elucidate the effect of coexisting components in the filler, sterilization time, and solid-to-filler ratio of prepackaged food on the amount of seasoning sorbed on solid food. To evaluate the mass transfer of seasonings in food, konjac or mackerel with either a sodium chloride solution or a model solution as a filler were prepackaged. The distribution coefficient of sodium chloride (i.e., the ratio of the amount of sodium chloride sorbed on the solid food to the concentration of sodium chloride in the solution) for konjac was approximately $0.76 \times 10^{-3} \text{ m}^3/\text{kg}$ and that for mackerel was approximately $0.40 \times 10^{-3} \text{ m}^3/\text{kg}$. These values are similar to those obtained when the model solution is used. Changes in sterilization time and solid-to-filler ratio did not significantly affect the distribution coefficients. The values of the distribution coefficients for commercial canned fish were similar to those obtained experimentally.

Keywords: distribution coefficient, sodium chloride, konjac, mackerel, prepackaged food

1. Introduction

The penetration of seasoning compounds such as saccharides and salts into food can change the taste and texture of the product. Therefore, considerable attention must be paid to the transportation of seasonings during food manufacturing. Although many processes are implemented based on experience and intuition, only a few are efficient. Therefore, a method that can be used to predict and control the transport of food seasonings from a scientific perspective would contribute to both large-scale food manufacturing and small-scale domestic cooking.

Analyses of distribution equilibria and diffusion rates are required to understand the transport of food seasoning. Studies have revealed the amounts of typical seasoning compounds sorbed on potatoes [1] and whale meat [2], and the amount of sodium chloride (NaCl) sorbed on starch gel, egg white gel, and vegetables[3]. Moreover, my previous study [4] reported the sorbed amounts and diffusion rates of typical seasoning compounds (i.e., glucose and NaCl) in models of gelled food (i.e., konjac and egg white gel [4]). In this study [4], the distribution coefficient is defined as the ratio of the amount of seasoning sorbed on the solid food to the concentration in the liquid solution. By calculating the values of the distribution coefficients, the amounts of specific seasoning compounds sorbed on the different foods were compared.

Prepackaged food with sterilization can be considered a closed system for substances because foodstuffs or seasoning compounds cannot be added after packaging. In this context, the conditions of the foodstuff and seasoning liquid (filler) may be important factors in sterilization. However, few systematic studies have been conducted from this perspective, and only one study on temporal changes in the amounts of sucrose and NaCl sorbed on canned fish is available [5].

In the present study, the mass transfer of seasoning compounds in prepackaged foods was measured. Prepackaged pouched foods were manufactured using konjac, which is a gel, mackerel, which has a histological structure, as a solid food, and NaCl as a typical seasoning compound. First, the effects of coexisting compounds, in addition to NaCl, were evaluated using a NaCl solution or a model solution as a filler. Subsequently, the effects of sterilization time and solid-to-filler ratio inside the package were examined, because the above-cited literature [5] did not investigate these parameters. The prepackaged food in this study was manufactured using varying NaCl concentrations, coexisting components in addition to NaCl, sterilization times, and solid-to-filler ratios. Commercially available canned fish manufactured under unknown conditions were also analyzed. The results were compared with those of experimentally manufactured prepackaged pouched foods.

The results of this study will facilitate the prediction and control of seasoning transport phenomena.

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2. Materials and Methods

2.1 Materials

Commercially available konjac (Consumers Co-operative Kobe, Kobe, Japan) and soy sauce (Kikkoman, Chiba, Japan) were purchased from a local supermarket in Kobe, Japan. According to the manufacturer's label, konjac was made from konjac corm and flour, and soy sauce was made from defatted soybeans. Frozen mackerel fillets were purchased from the fishery wholesaler Marutame Suisan (Amagasaki, Japan). Unfortunately, breed of mackerel is unclear (for example, chub mackerel or blue mackerel, and so on), because the author could not confirm it through the Marutame Suisan.

NaCl and sucrose were purchased from FUJIFILM Wako Pure Chemical Corporation (Osaka, Japan). Both NaCl and sucrose were of guaranteed reagent grade. Ion-exchanged water was used through this experiments. Ion-exchanged water was prepared by using a cartridge water deionizer G-10C (Organo Corporation, Tokyo), and its electric conductivity was confirmed to be no more than 2 $\mu\text{S}/\text{cm}$ by using a conductivity meter BB-5A (Organo). Ion-exchanged water was hereafter mentioned merely as "water."

Eight types of canned fish were purchased from a local supermarket in Kobe: two types of canned mackerel prepackaged with NaCl solution, which were manufactured by two different suppliers, mackerel canned with pure water, mackerel canned with soy sauce, sardines canned with NaCl solution, sardines canned with soy sauce, flaked tuna canned with soy sauce, and tuna fillets canned with soy sauce. These samples were selected based on variations in the fish and fillers.

2.2 Prepackaging of the food

Prepackaged food was prepared using a previously described method [6].

The konjac was pretreated by cutting it into cubes of approximately 10 mm and soaking them in abundant water for 12 h at 4°C to remove potential excess ingredients. The mackerel fillets were steamed at 100°C for 10 min using an FCCM202 Combi Oven (Fujimak, Tokyo, Japan) after thawing for 12 h at 4°C. The steamed mackerel fillets were approximately 80 × 70 mm and 8–10 mm thick, although they varied in size.

Approximately 130 g and 50 g of pretreated konjac or mackerel and filler, respectively, were placed into an RP-F retort pouch (140 × 180 × 38 mm; 12 μm polyeth-

ylene terephthalate/15 μm polyamide/7 μm Al/60 μm polypropylene; Toyo Seikan, Tokyo, Japan). NaCl solutions with concentrations ranging from 1×10^{-2} to 8×10^{-2} kg/kg (1–8% (w/w)) or model solutions were used as fillers. Model solutions were prepared from soy sauce, water, and sucrose in a weight ratio of 2:4:1. The pouch was sealed using a foot-operated impulse sealer Fi-400 (Fuji Impulse, Osaka, Japan).

The sealed pouches were sterilized in a hot shower for 35 min (120°C; pressurized atmosphere of 0.15 MPa read using a gauge) using a H130-C110 simulator retort (Toyo Seikan). During the sterilization process, the come-up and come-down times were 12 min and 6 min, respectively. In this report, the term "sterilization time" refers to the duration during which the temperature inside the simulator retort is maintained at 120°C.

The temperature at the geometrical center of the sealed pouch containing both solid food and filler was measured using an E-Val Flex wired thermocouple system (Erabu Japan, Tokyo, Japan), and the sterilization value, namely the F_0 -value, was calculated using ValSuite Pro ver. 5.2.0.10 (Erabu Japan).

To measure the temperature inside the pouch, a 1.2 mm diameter thermocouple (Erabu Japan) was inserted into the pouch using a GEJ13 rubber seal (Erabu Japan). The thickness inside the pouch was maintained at 15 mm using a GEM21 sensor holder (Erabu Japan), and a thermocouple was placed at the center of the 15 mm-thick pouch. The temperature of the filler was measured because it was difficult to insert the thermocouple into solid food (konjac or mackerel).

To evaluate the effects of sterilization time and solid-to-filler ratio, prepackaged food was manufactured under different conditions. The details of these conditions are described in the following sections.

Prepackaged food manufactured as described above is referred to prepackaged pouched food. Prepackaged pouched food was analyzed after storage at 25°C for more than seven days using a CSH-110 thermostat chamber (Espec, Osaka, Japan).

NaCl sorbed on konjac, mackerel, and other fish was extracted and analyzed using the methods described below. The NaCl concentration in the filler inside the pouch after storage was determined after filtration.

2.3 Variation of the sterilization time

The samples were sterilized for 35, 55, or 75 min. When the sterilization time was varied, the solid-to-filler ratio was fixed at 130 g/50 g, and the other conditions

were the same as those previously described.

2.4 Variation of the solid-to-filler ratio in the pouches

The solid-to-filler ratios in the pouches were 130 g/50 g, 50 g/130 g, and 50 g/130 g for konjac, and 130 g/50 g, 90 g/90 g, and 30 g/150 g for mackerel. The solid-to-filler ratio of 50 g/130 g for konjac was adopted as the inverse of the standard ratio of 130 g/50 g. However, in the case of mackerel, because the weight of a piece of steamed mackerel fillet is approximately 30 g, a solid-to-filler ratio of 30 g/150 g was adopted for the conditions in which the filler was larger than the solid. When the solid-to-filler ratios were varied, the sterilization time was fixed at 35 min, and the other conditions were the same as those previously described.

2.5 Extraction of NaCl from konjac

NaCl was extracted from konjac using a previously described method [4]. Briefly, konjac (5 g, precisely weighed) was ground using a mortar and pestle, and 50 mL of water was added to the mortar. After 30 min, the mixture was passed through No. 2 filter paper (Toyo Roshi Kaisha, Tokyo, Japan). The obtained filtrate was made up to a volume of 50 mL with water and was used for NaCl content analysis.

2.6 Extraction of NaCl from mackerel and other fish

NaCl from mackerel and other fish was extracted a method based on a previous study [7]. Briefly, 3 g of mackerel or other fish (precisely weighed) was homogenized with 30 mL of water for 20 s at 5,000 rpm using an ED-7 homogenizer (Nihon Seiki Kaisha, Tokyo, Japan). After 30 min, the mixture was passed through No. 2 filter paper. The filtrate was made up to a volume of 50 mL with additional water and used for analysis.

2.7 Analysis of NaCl content

The NaCl concentrations were determined using a SAT-500 salt analyzer (DKK-TOA, Tokyo, Japan). The injection volume for each sample was 200 μ L. This device could detect not less than 0.02% (w/v) NaCl in a solution. The NaCl content in the solid and the concentration in the filler were calculated from the values measured by the salt analyzer using a calibration curve.

2.8 Statistical analysis

Statistical analysis (one-way ANOVA and Tukey-

Kramer's multiple comparison test) of the distribution coefficient of the prepackaged mackerel containing NaCl filler solution, canned mackerel or sardines, and canned tuna was conducted using Microsoft Excel 2016.

3. Results and Discussion

3.1 Storage period of prepackaged konjac and mackerel before analysis

The chloride anion concentrations in the extracted solid and filler solutions were determined using a salt analyzer. The obtained values express the chloride anion content or concentration. However, sodium cations must penetrate solid foods simultaneously with chloride anions to satisfy the electrical neutrality requirement. Furthermore, the SAT-500 salt analyzer based on coulometric titration method is reported as one of the most reliable device for measuring NaCl in a previous literature [8]. Hence, the results of the chloride anion content obtained from these experiments can be regarded as representative of the NaCl content, when both NaCl solution and model solution used as filler. Hereafter, a representation of the NaCl content or concentration is used. This procedure is adopted by referring to a previous literature [9].

The diffusion coefficient of NaCl into steamed swordfish meat at 100°C is reported to be 0.15 cm²/h ($\approx 4.2 \times 10^{-9}$ m²/s) [10]. Assuming that the diffusion coefficient increases by 2 times for every 10°C increase in temperature [11], and the value of the diffusion coefficient at 120°C is 1.7×10^{-8} m²/s. Assuming that this value can be applied to the diffusion of NaCl into steamed mackerel meat, the Fourier number Fo [-] were calculated using Eq. (1) [12-14] as follows:

$$Fo = D_{\text{eff}} \cdot t/l^2, \quad (1)$$

where D_{eff} [m²/s] is the effective diffusion coefficient, l [m] is the characteristic length, and t [s] is the time.

Because steamed mackerel fillets had average thickness of from 8×10^{-3} m to 10×10^{-3} m, the Fourier number at 120°C for 35 min are calculated as 2.2 and 1.4, when characteristics length were assumed as 4×10^{-3} m and 5×10^{-3} m, respectively.

From the Fourier number, the dimensionless concentration (Θ), can be obtained, in order to estimate the progression of mass transfer. The value of $1-\Theta$ is defined as the ratio of NaCl content at center of an infinite slab to that at surface of slab. According to the Williamson-Adams chart for an infinite slab [15], the Θ value corresponding to Fourier number 1.4 is 0.04. When

the Θ value is 0.04, that is to say the value of $1-\Theta$ is 0.96, the NaCl content at the center of slab could reach 96% at surface of slab. Taking below two point into account, (1) the steamed mackerel fillet was a finite slab with dimensions of approximately 80 mm \times 70 mm \times 10 mm, (2) NaCl content in whole slab is higher than that at the center of slab, it would be reasonable to consider that the distribution of NaCl on mackerel fillet reaches equilibrium during sterilization process at 120°C for 35 min.

Yoshino and Iwata [5] determined the amounts of NaCl and sucrose sorbed on mackerel and tuna for canning and reported that the values reached 90% of the maximum 1 day after canning and hardly changed after 10 or 20 days. In preliminary experiments, I analyzed the temporal changes in the amount of NaCl sorbed on konjac or mackerel and the NaCl concentration of the filler for prepackaged pouched food stored at 25°C. These values did not change between storage days 1 and 7 (data not shown). The temporal change in the sorbed amounts determined via experimental calculations in the present study corresponds to the results by Yoshino and Iwata [5], suggesting that the mass transfer of seasoning compounds in prepackaged food is mostly complete by the end of the sterilization process. Therefore, prepackaged pouched food after storage at 25°C for more than 7 days was analyzed to assess the complete mass transfer of NaCl during this period.

3.2 NaCl distribution coefficients on konjac and mackerel in the prepackaged food

The distribution isotherms [i] of NaCl on konjac and mackerel in prepackaged pouched foods are shown in Fig. 1. Assuming that Henry's law can be applied to the distribution of NaCl on konjac and mackerel, Eq. (2) can be used to define the distribution coefficient of seasoning compounds in solid foods, K_D [m^3/kg]:

$$q = K_D \times C, \quad (2)$$

where C [kg/m^3] is the NaCl concentration of the filler inside the pouch after storage and q [kg/kg] is the NaCl content in solid phase. Because NaCl was not detected in konjac and mackerel after pretreatment, the initial concentration of NaCl in konjac and mackerel was regarded as 0 kg/kg . Similar observation about initial concentration of NaCl in fish is reported in the literature [9].

If distribution equilibrium between food and liquid is assumed, a certain amount of NaCl could remain in residue after extraction. However, in this report, amount of NaCl in extract obtained by the method described in

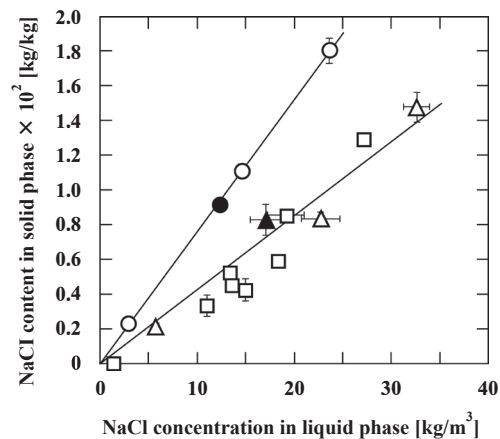


Fig. 1 Distribution isotherm of sodium chloride on konjac (circles), mackerel (triangles), and other fish (squares). Sodium chloride solution (empty symbols) and model solution (filled symbols) were used as fillers for konjac and mackerel. The results are expressed as the average \pm standard deviation ($n = 3$). The solid lines express linear regression of the q value on the C value with regard to distribution of NaCl on konjac and mackerel.

Section 2.5 and 2.6 were used for calculation of the q value, and NaCl remained inside the residue were not considered. This is because that distribution characteristics of NaCl on homogenized fish meat might differ from original fish meat due to destruction or injury of tissue and cell by homogenization. Moreover, in previous research, total amounts of NaCl sorbed on chicken meat [16] and root vegetables [7] were determined based on NaCl concentration of supernatant obtained after homogenization. Taking above into consideration, it is assumed that NaCl were taken up until distribution equilibrium reached, while all amounts of NaCl were removed from ground or homogenized food in extraction procedure.

When Kawasaki *et al.* [17] examined extraction of NaCl from salted cod roes in different extraction time, extracted amounts did not change after 5 min. Because they extracted whole salted cod roes, whose diameter is generally considered to be *ca.* 1.0 mm, without any homogenization, time required for extraction would be shorter in my experimental procedure, in which homogenization procedure were employed. Extraction time 30 min were considered to be sufficient to extract NaCl from ground or homogenized food.

When NaCl solution was used as a filler, the distribution coefficients of NaCl on konjac and mackerel, calculated using three different NaCl concentrations, were $0.76 \pm 0.00 \times 10^{-3}$ and $0.40 \pm 0.05 \times 10^{-3} \text{ m}^3/\text{kg}$ (average

\pm standard deviation, $n = 3$), respectively. The two solid lines in Fig. 1 represent the linear regression of the q value on the C value for the distribution of NaCl on konjac and mackerel. The difference in the distribution coefficients may reflect the physical structure or chemical composition of the gel-structured konjac and histologically structured mackerel. The relationship between ingredient composition and distribution coefficients of fish is discussed in a later section.

The model solution, prepared as described in the previous section, was also used as a filler. The NaCl contents of the original soy sauce and the model solution before sterilization were $1.74 \times 10^2 \text{ kg/m}^3$ and 45.8 kg/m^3 , respectively, as determined using the SAT-500 salt analyzer. When the model solution was used as the filler, the distribution coefficients of NaCl on konjac and mackerel were $0.74 \pm 0.01 \times 10^{-3}$ and $0.48 \pm 0.03 \times 10^{-3} \text{ m}^3/\text{kg}$, respectively, and these values were nearly consistent with those predicted from the distribution isotherms using NaCl solution (Fig. 1).

The model solution in the present study contains sucrose and ingredients originated from soy sauce in addition to NaCl. From the viewpoint of taste of food, possible interaction between saccharides (sweet taste) and NaCl (salt taste) might be paid great attention. However, evaluating the effects of coexisting components on the distribution coefficients is difficult. For example, previous studies [18–20] on the amounts of sorbitol and NaCl sorbed on walleye pollock revealed that the sorbed amount of NaCl on fish meat was hardly affected by the presence of sorbitol; however, the sorbed amount of sorbitol was affected by the sorbitol concentration and the coexistent NaCl concentration. These studies indicate that certain coexisting seasoning compounds can be ignored when considering the sorbed amounts of certain seasoning compounds. In addition, my previous study [4], which focused on distribution of glucose (sweet taste) and NaCl (salt taste), showed that the distribution coefficient of glucose on egg white gel was lower in a bi-component system containing both glucose and NaCl than in a single-component system. Because the distribution coefficient of NaCl did not change in the bi-component system compared with the single-component system, it is suggested that a change in the distribution coefficient does not always occur when a multicomponent system is used.

Considering the above-mentioned research, in the present study, the coexistence of sucrose and other compounds may not have significantly affected the amount of

NaCl sorbed on konjac and mackerel, suggesting that it is possible to predict the amount of NaCl sorbed in the model solution from the experimental results obtained using the NaCl solution. This also supports that Henry's law can be applied to the distribution of NaCl on konjac and mackerel.

3.3 Effects of the sterilization time and solid-to-filler ratio on the distribution coefficients

Figure 1 shows that the sorbed amounts of the multi-component solutions can be predicted from those of the single-component solutions. However, the prepackaged foods that are the subjects of comparison may be manufactured by each supplier under different conditions, such as the sterilization time and solid-to-filler ratio when manufacturing. Herein, I focused on the sterilization time and solid-to-filler ratio and evaluated the effects of these parameters on the sorbed amounts of NaCl.

Prepackaged pouched foods were prepared using various sterilization times and solid-to-filler ratios. When sterilization times of 35, 55, or 75 min were used, the solid-to-filler ratio was fixed at 130 g/50 g. As the solid-to-filler ratios in the pouches were varied (130 g/50 g, 90 g/90 g, 50 g/130 g for konjac; 130 g/50 g, 90 g/90 g, or 30 g/150 g for mackerel), the sterilization time was fixed at 35 min.

In prepackaged food, the sterilization value, F_0 -value [min], is frequently calculated. The F_0 -value is defined as the equivalent sterilization time at 121.11°C or 250°F of the actual sterilization time at a given temperature, calculated for the Z -value as 10°C [ii]. The F_0 -value [min] were calculated as Eq. (3) using the software ValSuite Pro ver. 5.2.0.10:

$$F_0 - \text{value} = \sum_{t_1}^{t_2} 10^{\frac{T-121.11}{10}} \times \Delta t \quad (3)$$

where T [°C] is the temperature, t_1 [min] and t_2 [min] is the beginning and finishing time for calculating the F_0 -value, Δt [min] is the time interval for measuring temperature.

The sterilization values, namely, the F_0 -values, for each manufacturing condition are listed in Table 1. The sterilization value increased by approximately 20 min when sterilization time was increased by 20 min. Moreover, when the solid-to-filler ratio was decreased from 130 g/50 g to 30 g/150 g by increasing the amount of filler in the pouch, sterilization values did not increase by more than 30. These results indicate that prolonging

Table 1 Sterilization values (F_0 -value [min]) based on different sterilization times and solid-to-filler ratios.

		Sterilization values, F_0 -value [min]	
		Konjac	Mackerel
Sterilization time [min] *	35	26	20
	55	45	38
	75	61	58
Solid-to-filler ratio [g/g] **	130/50	26	20
	90/90	30	25
	50/130, 30/150 ***	29	28

* The solid-to-filler ratio was fixed at 130 g/50 g.

** The sterilization time was fixed at 35 min.

*** Ratios of 50/130 and 30/150 were adopted for konjac and mackerel, respectively.

sterilization had a greater impact on the sterilization value than increasing the amount of filler in the pouch.

The distribution coefficients of NaCl in the food manufactured under the aforementioned conditions were calculated. These prepackaged food pouches were stored at 25°C for more than 7 days before analysis. The dependences of the distribution coefficients on sterilization time and solid-to-filler ratio are shown in Fig. 2a and 2b, respectively. Sterilization time and solid-to-filler ratio had little effect on the distribution coefficients of NaCl in konjac and mackerel. Fig. 2b shows that the interiors of the prepackaged konjac and mackerel pouches reached NaCl distribution equilibrium after seven days had elapsed. Briefly, NaCl was sorbed on solid food until a certain distribution coefficient value was reached, regardless of the solid-to-filler ratio inside the pouch.

3.4 Distribution coefficients of NaCl in commercially available canned fish

Eight types of commercially available canned fish were selected, and the NaCl content of the solid and concentration of the filler were analyzed. The results and the distribution coefficients are shown in Fig. 1 and Table 2, respectively

In canned mackerel manufactured without NaCl as a filler, NaCl was not detected in the solid mackerel; however, a small amount was detected in the filler. The distribution coefficient of this sample was defined as 0 m³/kg (Fig. 1 and Table 2). The distribution coefficients of the two types of canned tuna were 0.48 × 10⁻³ and 0.45 × 10⁻³ m³/kg for canned flaked tuna with soy sauce and canned tuna fillets with soy sauce, respectively, that is, slightly higher values than those of the other five types

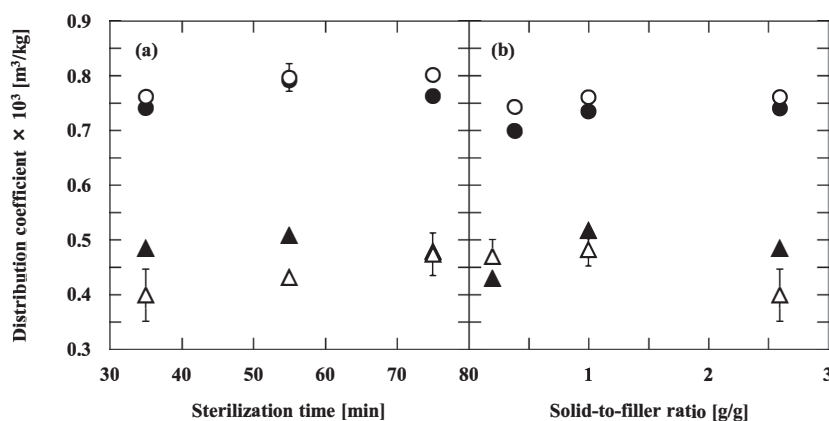


Fig. 2. Dependence of the distribution coefficients on (a) the sterilization time and (b) the solid-to-filler ratio. Konjac (circles) and mackerel (triangles) were used as the solids, and sodium chloride solution (empty symbols) and the model solution (filled symbols) were used as fillers. The results for sodium chloride solution are expressed as the average \pm standard deviation ($n = 3$).

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of canned fish, which contained mackerel or sardines (Table 2). This difference is discussed later.

The main nutritional factors used to compare the chemical composition of the fish are cited from the “Standard Tables of Food Composition available at the Ministry of Education, Culture, Sports, Science and Technology, Japan website [iii]”, and listed in Table 3. As shown, chub mackerel was selected as a representative mackerel species, yellowfin tuna was selected as the main raw material for canned flaked tuna with soy sauce, and bigeye tuna was selected as the raw material for canned tuna fillet with soy sauce.

The moisture contents of yellowfin and bigeye tuna were higher than those of chub mackerel and sardines. Because NaCl dissolves in the water portion of fish meat, the moisture content may determine the distribution coefficient value. In addition, because NaCl dissociates

into sodium cations and chloride anions, these ions can be sorbed on the electrically charged proteins. As presented in Table 3, the protein content of yellowfin and bigeye tuna was higher than that of chub mackerel and sardines, as reflected in the corresponding distribution coefficients presented in Table 2.

As mentioned above, the distribution coefficient of a seasoning compound may be affected by the chemical composition of the solid food and its histological structure. Ueyanagi [21] reported that sorbed amount and diffusion rate of NaCl into cutlass fish was much lower than those into other fish (cod, sea bream, skipjack tuna, horse mackerel, chub mackerel). These results were attributed to the fact that cutlass fish contained much more collagen in their tendon tissue than the other five fish species, resulting in a lower sorbed amount and diffusion rate.

Table 2 Distribution coefficients of mackerel prepackaged with NaCl solution and commercially available canned fish.

	Distribution coefficient [m ³ /kg]	Group for statistical analysis
Mackerel prepackaged with NaCl solution*	0.40×10^{-3}	Group-A
Mackerel canned with NaCl solution**	0.33×10^{-3}	Group-B
Mackerel canned with NaCl solution**	0.30×10^{-3}	Group-B
Mackerel canned with pure water	0***	—
Mackerel canned with soy sauce	0.28×10^{-3}	Group-B
Sardines canned with NaCl solution	0.39×10^{-3}	Group-B
Sardines canned with soy sauce	0.32×10^{-3}	Group-B
Flaked tuna canned with soy sauce	0.48×10^{-3}	Group-C
Tuna fillet canned with soy sauce	0.45×10^{-3}	Group-C

* The value of distribution coefficient of mackerel prepackaged with NaCl solution is shown as average value calculated from three empty triangle symbols shown in Fig. 1.

** These two commodities are manufactured by two different suppliers.

*** Because any NaCl was not detected in the solid mackerel, distribution coefficient of this sample was calculated as 0 m³/kg.

Table 3 Nutrition factors pertaining to various fish species [iii].

	Content [g/100 g]			
	Moisture	Protein	Lipid	Carbohydrate
Chub mackerel*	62.1	20.6	16.8	0.3
Sardines	68.9	19.2	9.2	0.2
Yellowfin tuna**	74.0	24.3	1.0	Tr****
Bigeye tuna***	72.2	25.4	2.3	0.3

* Chub mackerel was selected as the representative mackerel.

** Yellowfin tuna was selected as the main raw material of canned flaked tuna with soy sauce.

*** Bigeye tuna was selected as the raw material of canned tuna fillet with soy sauce according to the label of the product.

**** “Tr” means “trace,” indicating that “the food certainly contains this component, but the value does not reach the minimal required value.”

Jafari *et al.* [22] pointed out that most marine collagen is distributed in fish skin, bone, cartilage, and scale. Previous reports have shown that the collagen content in mackerel skin, tuna skin, and sardine scale is 6.4% [23], 5.5% [24], and 1.25–3% [22], respectively. Because Ueyanagi [21] noted that the collagen content of cutlass fish was much higher than that of the other fish examined, the collagen content of three fish (mackerel, tuna, and sardine) in the present study might be lower than that of cutlass fish. Ueyanagi [21] also pointed out that distribution and diffusion of NaCl into fish were affected by tendon tissue and collagen. Because the collagen content of mackerel, tuna, and sardine was lower than that of cutlass fish, the histological structure of the three fish might not differ more than that of the cutlass fish, suggesting that the NaCl distribution coefficients are affected by the moisture and protein content of the fish than histological structure. Another previous research [25] also reported that diffusion rates of salts in tuna meat along perpendicular and parallel to muscle fiber were almost the same each other. While distribution coefficients of salts (NaCl) on mackerel, sardine and tuna might be affected by the hydrophilic component contents such as moisture and protein, their diffusion rates in these three fish might hardly be affected by anisotropy of fish meat or muscle structure.

Three groups are prepared for statistical analysis; namely, the distribution coefficients of the prepackaged mackerel with NaCl filler solution ($0.40 \pm 0.05 \times 10^{-3} \text{ m}^3/\text{kg}$, Group-A, empty triangle symbols shown in Fig. 1 and Table 2), the canned mackerel or sardines ($0.33 \pm 0.04 \times 10^{-3} \text{ m}^3/\text{kg}$, Group-B, shown in Table 2), and the canned tuna ($0.46 \pm 0.04 \times 10^{-3} \text{ m}^3/\text{kg}$, Group-C, shown in Table 2). The moisture and protein content were considered for dividing Group-B and Group-C, and the distribution coefficient of mackerel canned with pure water (Table 2) was excluded from Group-B, because of its irregularity.

Statistical analysis (one-way ANOVA) were done among Group-A, Group-B and Group-C, and the results are shown in Table 4. The results of one-way ANOVA show that there are significant differences between the

three groups ($F = 8.34$, degrees of freedom = 2/7, $p < 0.05$). When Tukey–Kramer’s multiple comparison test were done as post-hoc test between the three groups, significant difference was detected only between Group-B and Group-C ($p < 0.05$). However, because the difference in the distribution coefficient was close to the null hypothesis, it is suggested that only slight differences might exist in the distribution coefficients among the prepackaged mackerel containing NaCl filler solution (Group-A), canned mackerel or sardines (Group-B), and canned tuna (Group-C).

As mentioned in the previous section, sterilization time and solid-to-filler ratio hardly affected the distribution coefficient. These results suggest that it is possible to estimate the amount of sorbed NaCl in canned fish, regardless of fish species, from experimental data obtained from samples containing NaCl solution and one species of fish (mackerel).

4. Conclusions

Prepackaged pouched food containing konjac or mackerel as solid food and NaCl or a model solution as the filler was prepared. When the distribution coefficients were calculated from the NaCl content of the solid food and the NaCl concentration of the filler, the values of the distribution coefficients for the NaCl and model solutions were similar. Sterilization time and solid-to-filler ratio had little effect on the distribution coefficient. The distribution coefficients of commercially available canned fish were similar to the experimental results obtained using the mackerel and NaCl solutions.

Nomenclature

- C : NaCl concentration in liquid phase, kg/m^3
 D_{eff} : effective diffusion coefficient, m^2/s
 Fo : Fourier number, –
 F_0 : sterilization value, min
 K_D : distribution coefficient, m^3/kg
 l : characteristic length, m
 q : NaCl content in solid phase, kg/kg

Table 4 Results of one-way ANOVA.

	Sum of squares	Degrees of freedom	Mean square	F	p
Group	2.78×10^{-2}	2	1.39×10^{-2}	8.34	1.41×10^{-2}
Residuals	1.17×10^{-2}	7	1.67×10^{-3}		

- T : temperature, °C
 t : time used in Eq. (1), s
 t_1, t_2 : time used in Eq. (3), min
 Δt : time interval used in Eq. (3), min
 Θ : dimensionless concentration, -

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