Development of Real-Time Measurement of Salinity Concentration to Evaluate Suitable Food Dipping States During Salting

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For this study, we developed a novel real-time monitoring system using a stainless steel electrode to assess NaCl osmosis in the food interior by measuring electrical impedance. The NaCl penetration into agar gel sprayed with NaCl on the surface was evaluated using impedance. As the measured position of the electrode moves downward, a longer time is needed to obtain a constant impedance value. Measurement of the chloride concentrations in the model food that had been cut into four pieces (surface, upper, middle, and lower parts) revealed an extremely strong relation between the equilibrium period of the impedance value and the inner chloride concentrations of the model. Results confirmed that a similar impedance value was obtained if the concentration of NaCl sprinkled on the top of the gels was the same irrespective of points measured using the electrode. These results demonstrate that this impedance measurement method using an LCR meter is useful for real-time monitoring of NaCl osmosis in the food interior.

Keywords : Penetration, Real-time measurement, Salting process

1 INTRODUCTION

Salt, NaCl, a fundamentally important seasoning for cooking, affects not only the taste of dishes but also the texture of food because of dehydration and tightening of meat and fish through denaturation of their proteins¹⁻⁴⁾. Nevertheless, excessive NaCl intake causes disease. For that reason, reduction of NaCl intake is often recommended⁵⁾. Heretofore, NaCl contents in food have been ascertained through analyses of constituents of water extracted from food materials. However, according to this procedure, the penetration of NaCl into the food interior cannot be evaluated in real time. Based on past experience, one might dip foods into NaCl for a long period, thereby leading to excessive NaCl intake. For this study, we used a stainless steel electrode to measure electrical impedance. Thereby, we developed a novel real-time monitoring system for NaCl osmosis in the food interior.

2 MATERIALS AND METHODS

2.1 Model food preparation

Two gels made from agar and egg white were used as model foods. To prepare the agar gel, agar powder (Kanten Cook; Ina Food Industry Co. Ltd.) was added to distilled water at 0.8% (w/w) concentration. It was then dissolved by boiling. The solution (25 g) was solidified in a glass case (length 25 mm × width 25 mm × height 50 mm) and was stored for 30 min at room temperature (25°C). Egg white powder (dried albumen K type; Kewpie Egg Corp.) was stirred for 30 min in distilled water at 7.5% (w/w) concentration. After filtration through a tea strainer, the filtrate (25 g) was poured into a glass case (25 mm × 25 mm × 50 mm). After covering the top of the case, the egg white solution was heated in a boiling steamer for 10 min and was steamed in a pan for

another 30 min. Subsequently, it was solidified by cooling at room temperature for 30 min. All gels (25 mm × 25 mm × 35 mm) were used for measurement while they were still in the glass case.

2.2 Impedance measurement

The stainless steel rod electrodes that had been film-coated by insulating spray were inserted into the food interior to measure the impedance of the surface, upper, middle, and the lower regions of the food (Figure 1). After sprinkling various amounts of NaCl all over the gel surfaces, the impedance values of gels were measured using an Inductance Capacitance and Residence (LCR) meter (3523-50; Hioki E. E. Corp., Japan). The sample impedance

Figure 1 Stainless steel stick electrode used for impedance measurement. Insulation spray coated onto electrodes for measurement of the impedance value of part of foods: A, surface electrode; B, upper position electrode; C, middle position electrode; D, lower position electrode.

Figure 2 Schematic diagram showing the experimental apparatus for measurement of impedance by an LCR meter.

was measured at a frequency of 1 kHz at 1 V. Figure 2 portrays a schematic diagram of experimental apparatus used for the measurement of impedance by an LCR meter. When salt dissolves in the food surface and penetrates into the interior, the impedance value decreases gradually. Because NaCl penetrates into food and gradually diffuses, the impedance value keeps decreasing, but after a certain time the amount of change becomes negligible. We investigated the time within which the change amount is within 1 and set the measurement time. The results of the impedance measurement up to 1200 s after spraying 0.5 g NaCl on the agar surface are taken as an example. Results show that the impedance value at 900 s was $184.0 (\pm 42.2)$. The impedance value at 1200 s was $180.3 (\pm 40.4)$. These differences were comparable to the differences found between samples. We thought that no problem existed. Therefore, the measurement time was set as follows. After sprinkling 0.5 g of NaCl on the gel surface, impedance values after 15 min for the surface electrode, 40 min for the upper electrode, and 75 min for the middle electrode were obtained. Similarly, for the 1.0 g and 2.0 g NaCl, the impedance value was set to 15 min for the surface electrode, 60 min for the upper electrode, and 120 min for the middle electrode. After allowing the NaCl to permeate for a given time, the NaCl remaining on the surface of the agar gel was flushed with distilled water on a Petri dish. After the gels were cut into pieces at each electrode height, the chloride ion concentration was ascertained^{6, 7)}. The obtained measured values were converted to the NaCl amount. After the washed NaCl on the Petri dish was heated on a hot plate, the weight was measured as dry solid NaCl by evaporating the water.

2.3 Food salinity measurement using impedance

We prepared four agar gels containing 1.0, 3.0, 5.0, 7.0, 9.0, and 11% of NaCl (w/v) at the measurement position to ascertain the inner concentrations of NaCl in the gels (Figure 3). The impedance value after 40 min was measured. The impedance value of each

Figure 3 Schematic diagram showing the agar containing part of NaCl and the electrode position.

part was compared at the same concentration.

3 RESULTS AND DISCUSSION

A high NaCl concentration is set in this study because, reportedly, NaCl is sprinkled on the surface with 12–18% against plum when making pickles⁸⁾, 2–18% for vegetables when preparing pickles⁹⁾, and 7% for fish when making dried fish¹⁰⁾. Therefore, at the start of processing, NaCl does not dissolve but instead exists as a layer on the food surface. In this experiment, to model the actual process of food processing, 0.5, 1.0, and 2.0 g were sprinkled on the agar gel surface so that NaCl remained on the agar gel surface even after the impedance measurement was completed.

When NaCl is sprinkled on the food surface, it dissolves into the moisture on the surface of food, which becomes saline; thereafter, it gradually penetrates into food. At that time, the electric resistance decreases, but it varies gradually. We studied how NaCl is dissolved on the food surface by measuring the change of the impedance value on the gel surface using an LCR meter¹¹⁾. The impedance value for 900 s after adding NaCl to the agar gel surface was almost equal to that with addition of 0.5 and 1.0 g salt, but the impedance value with 2.0 g salt was lower than the others (Figure 4). These results suggest that the amount of added NaCl affects the impedance values at the gel surface.

Figure 5 presents impedance values associated with the penetration of the NaCl in the agar gel after sprinkling different amounts of NaCl to the agar gel. Furthermore, the length of time during which the same impedance value is indicated as the standard deviation. When sprinkling NaCl on the food surface, the impedance value decreases gradually. The impedance on the gel surface became almost constant after 15 min, irrespective of the added NaCl amount. The impedance at the upper site of 1.0 and 2.0 g NaCl addition reached nearly constant after 60 min. However, with the addition of 0.5 g of NaCl, a nearly constant value was obtained after 40 min. With 1.0 and 2.0 g salt addition to the middle site, the impedance value was obtained as an almost constant value after 120 min. In the case of adding 0.5 g of salt, a constant value was obtained after 75 min. Results indicate that the time necessary for the impedance value of the middle site to stabilize is twice that of the upper site. The equilibration time with 0.5 g of NaCl addition was probably short because the small amount of salt was dissolved

Figure 4 Impedance values after addition of 0.5–2.0 g NaCl were measured at the gel surface:

- , impedance after 0.5 g NaCl added to the agar surface;
- ◐, impedance after 1.0 g NaCl added to the agar surface;
- , impedance after 2.0 g NaCl added to the agar surface.

Figure 5 Changes of impedance with various amounts of added NaCl at different measurement positions.

Impedance values after addition of 0.5-2.0 g NaCl were measured at four locations of gels: surface, upper, middle, and bottom.

easily and diffused quickly to the agar. It was impossible to obtain a stable impedance value in the lower site. This behavior must be different from the diffusion mechanism of NaCl at the upper and middle site.

Impedance values on the upper part after addition of 0.5, 1.0, and 2.0 g of NaCl on top of agar gels were, respectively, 112, 76, and 67 Ω (Figure 5). Impedance is an electrical resistance value that has negative correlation to the penetration amount of NaCl. Therefore, the addition of 0.5 g of NaCl showed the highest impedance value obtained in the study.

Impedance values on the middle part after addition of 0.5, 1.0, and 2.0 g of NaCl on top of agar gels were, respectively, 114, 57, and 59 Ω (Figure 5). In the experiment using the middle electrode, the impedance values obtained by adding 1.0 g and 2.0 g of NaCl to the agar surface were equal. Because these impedance values are approximately equal values of about 50 Ω , the internal NaCl concentration might be saturated. However, the impedance value obtained by adding 0.5 g of NaCl to the agar surface was about 100 Ω at both the upper and the middle electrode, which suggests that 0.5 g of NaCl had an insufficient amount of NaCl to penetrate to the middle electrode.

Additionally, we succeeded in visualizing the penetration behavior of NaCl into agar gel by spraying NaCl on the surface of agar gel containing silver nitrate¹²⁾. Results confirmed that electrical impedance measurement is a useful tool to monitor NaCl penetration.

Subsequently, we examined the correlation between the impedance value of the agar gel and the NaCl concentration. NaCl was allowed to penetrate the food until the equilibrium time of each electrode. Then the agar was cut at the position of the electrode. After the salinity concentrations of each agar were measured, the amount of NaCl per 25 g of agar was calculated (Figure 6). The amount of NaCl remaining on the agar gel surface is portrayed in Figure 7. The amounts of NaCl at the agar gel surface were 0.11 g (addition of 0.5 g of NaCl), 0.15 g (1.0 g), and 0.15 g (2.0 g) at the equilibrium time on the surface part electrode. Amounts of NaCl at the upper position of agar gel were 0.05 g (addition of 0.5 g of NaCl), 0.20 g (1.0 g), and 0.23 g (2.0 g) at the equilibrium time on the upper electrode. Amounts of NaCl at the middle position of agar gel were 0.03 g (addition of 0.5 g of NaCl), 0.05 g (1.0 g),

Figure 6 NaCl concentrations of agar gels.

Following the sprinkling of various amounts of NaCl on the agar surface, the agar gels were incubated by reaching equilibrium time at the surface (A), upper (B), and middle (C) electrodes. Gels were cut into four pieces: surface (white), upper (light gray), middle (dark gray), and lower parts (dotted); the NaCl concentrations were measured at surface, upper, middle, and lower positions.

Figure 7 Remaining amounts of NaCl on the agar gel surface.

Following the sprinkling of various amounts of NaCl on the agar surface, the agar gels were incubated by reaching equilibrium time at the surface (A), upper (B), and middle (C) electrodes.

and 0.09 g (2.0 g) at the equilibrium time on the middle electrode. These results demonstrate that the amounts of NaCl on three electrodes by addition of 0.5 g were lower than those by addition of 1.0 g or 2.0 g of NaCl. The results agree with the impedance value. The total NaCl concentrations (the sum of the surface, upper, middle, and lower parts) were compared at each equilibrium time. By addition of 1.0 and 2.0 g of NaCl to the agar gel, the amount of NaCl increased as time passed, but 0.5 g NaCl increased only slightly. As the penetration time increased, the amount of NaCl remaining on the food surface decreased (Figure 7). Results show that the relation between amount of NaCl in the agar gel and the electrical impedance measurement is high.

We also measured the penetration behavior of NaCl on egg white gel. The equilibrium time increased along with the measured points of the electrode from the upper part of the gel to the lower part. Furthermore, a close relation was found between the chloride ion concentration and electrical impedance. The method described herein is applicable not only to agar gel, but also to other gels.

We prepared an agar gel containing NaCl (1.0, 3.0, 5.0, 7.0, 9.0,

Figure 8 Impedance in agar gels with various concentrations of NaCl. We prepared agar gels containing NaCl of 1.0, 3.0, 5.0, 7.0, 9.0, and 11%, respectively, at upper, middle, and lower electrode contact positions. The impedance of the gel at each position was measured after 40 min.

and 11%) for which upper, middle, and lower positions contact with an electrode. The impedance value of the gel was measured at each position. To evaluate the impedance values inside the food, only the results of the upper electrode, the intermediate electrode, and the lower electrode are presented in Figure 8. Results show that impedance values depend on the NaCl concentration, but not on the measurement position. As the NaCl concentration increased, the impedance value decreased gradually. However, when the NaCl concentration was higher than 5%, the change in the impedance value became small. Although the measurement methods were somewhat different, we tried to take measurements when saline having a concentration of 1.0–26% was added to the surface of the agar gel^[13].

Even in that case, the difference in impedance values was as slight as 15–26%. The results suggest that the electrical impedance method can evaluate the NaCl concentration in model foods with NaCl concentration up to 7%. According to the food ingredient table, the NaCl equivalent amount in food is 4.3% for turnip and radish pickles and 0.9 to 6.1% for dried fish^[14]. The impedance method is regarded as usable for this processing, which uses much NaCl. However, the NaCl equivalent amount of the plum pickle was 19.3%^[14]. Furthermore, it is important to construct a system that can quantify high-salinity foods such as plums. In conclusion, results demonstrate that our impedance measurement method using the LCR meter can monitor NaCl penetration in the food interior in real time, even at a low NaCl concentration range.

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