Measurement System for Solubility and Osmosis of Salt in Food

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We examined solubility differences on food surfaces according to salt particle diameter, which revealed that the salt diameter affects its solubility. Furthermore, we developed a new evaluation system uses electric impedance for non-destructive measurement of the dissolution state of salt on food.

Key Words : Solubility, Penetration, Salt, Electric impedance

1 INTRODUCTION

Salt, which is necessary for cooking, affects not only the taste of prepared dishes but also the texture of food by dehydration¹⁾. Recently, salt including bittern components with >1000 μm diameters has become commercially available in addition to high-purity salt with 300-600 μm ^{2,3)}. The texture and taste of dishes prepared with these salts differ from those of usual salt. The differences in particle size and/or purity of salt seem to affect the food properties because salt with larger particles is difficult to dissolve. It penetrates more slowly into food than usual smaller particle salts. The usual analytical method to measure NaCl concentration in food is by titration with silver nitrate solution⁴⁾ and atomic absorption spectrometry¹⁾ against food extracts. The dissolution state of salt on the food surface was not available for conventional and scientific measurements. This study examined the effects of salt diameter on solubility on the food surface. A novel non-destructive and real-time monitoring system was developed to assess the solubility and osmosis of salt by measurement of electric impedance.

2 MATERIALS AND METHODS

2.1 Salt sample preparation

Two kinds of commercially available salt with large and small particles were cleansed with ethanol and were then dried. The salt was filtered and classified into 10 groups by particle size (Table 1). The ingredients of each type of salt were the same (NaCl only). We classified these 10 groups into 4 large particle salt groups (1400-1700, 1180-1400, 1000-1180, and 850-1000 μm), 3 middle particle salt groups (710-850, 600-710, and 300-600 μm), and 3 small particle salt groups (250-300, 212-250, and 150-212 μm). The large particle groups are equivalent to commercially available bittern components, middle to general salts, and small to spray-dried salts, respectively.

2.2 Preparation of the model food

Three gels were used as model foods: agar gel (gel A), gelatin

Table 1 Particle sizes of 10 groups of salt used for this study

Group No.	Salt particle size (μm)
1	1400-1700
2	1180-1400
3	1000-1180
4	850-1000
5	710-850
6	600-710
7	300-600
8	250-300
9	212-250
10	150-212

gel (gel B), and tofu gel (gel C). Gel A was prepared using the following methods. Agar powder (Kanten Cook; Ina Food Industry Co. Ltd.) was dissolved in distilled water at 0.8% or 1.5% (w/w) concentrations. This solution was boiled and poured into a plastic case (25 mm $\times$ 25 mm $\times$ 12 mm) by 5 g. Then it was placed for solidification at room temperature for 0.5 hr. The gelatin powder (Jelice; Maruha Nichiro Food Corp.) was mixed with distilled water at 10% or 15% (w/w) concentrations. Then it was boiled and poured into a plastic case (25 mm $\times$ 25 mm $\times$ 12 mm) by 5 g, and placed in a refrigerator for 0.5 hr (gel B). Gel C was prepared using the following procedure. Glucono-delta-Lactone (Wako Pure Chemical Industries Ltd.) was dissolved in plain soybean milk (Organic soybean milk; Marusan-AI Co., Ltd.) at 0.6% or 1.0% (w/w). This solution (5 g) was heated in a glass case (25 mm $\times$ 25 mm $\times$ 12 mm) at 70°C for 0.5 hr. Then it was solidified by cooling.

2.3 Impedance measurement

By putting stainless steel electrodes (contact area of the gels; 23 mm wide, 8 mm long) at both ends of gels A-C, a test piece for measurement was made (25 mm interelectrode distance). After sprinkling sufficient amounts of salts on the gel surface in each cells, the impedance values of gels were measured using an LCR meter (3523-50; Hioki E. E. Corp., Japan) at 24°C (room

temperature). Figure 1 shows the grams of the salt sprinkled on gel surfaces. The sample impedance was measured at a frequency of 1 kHz at 1 V (Figure 2).

2.4 Solubility measurement of the salt in water solution

We dissolved 28 g of NaCl in 100 ml of distilled water and made NaCl solution at 28%. Then 1.5 g of a salt sample (see “2.1 Preparation of the salt samples”) was added to 50 ml of 28% (w/v) NaCl solution, which was warmed to 25°C and stirred in 100 rpm⁵⁾. The density was measured every 30 s in a refractometer for 390 s. Then the average was calculated from three independent tests.

3 RESULTS AND DISCUSSION

Salt sprinkled on the food surface is dissolved in water on the food surface, which decreases its electrical resistance. Therefore, we studied how salt is dissolved on the food surface by measuring the instantaneous change of the impedance value using an LCR meter. Figures 3-5 show changes of the impedance value with sprinkling of 10 groups of salts with different particle sizes on 0.8% gel A. For smaller salt particles, the decrease of impedance value occurred more rapidly, which indicates that the salt particle size influences its solubility on the food surface. The decrease of the impedance level of salt with large particles occurred slowly: large particles took more time to dissolve (Figure 3). However, changes in the impedance value of salt with small particles were quite low, which suggests that particle size differences of these salts did not exert a strong effect (Figure 5).

We sprinkled four groups of salts, which were with 1180-1400, 600-710, 300-600, and 150-212 μm of particle sizes, on surfaces of 10% gel B and 1.0% gel C, and measured their impedance levels (Figure 6 and 7). The salts with smaller particles dissolved quickly. Their impedance levels on both gels decreased as rapidly as they did on gel A.

To examine whether the gel composition has any effect on

Figure 1 Schematic diagram of experimental apparatus for measurement of impedance by an LCR meter.

Figure 2 Grams of salt sprinkled on the gel surface.

decreasing the rapidity of impedance change, we measured the rate of salt dissolution on various gels using particles of equal size. The changes of impedance values in sprinkled salt with diameters

Figure 3 Impedance values of large particle salts on 0.8% gel A.

Figure 4 Impedance values of middle particle salts on 0.8% gel A.

Figure 5 Impedance values of small particle salts on 0.8% gel A.

Figure 6 Impedance values of four salts with different size particles on 10% gel B.

Figure 7 Impedance values of four salts with different size particles on 10% gel C.

Figure 8 Impedance values of salts with diameter between 1180-1400 μm on five gel surfaces.

at 1180-1400 and 150-212 μm on all gels are shown respectively in Figure 8 and 9. These results suggest that differences in the composition and density of the gel affected the rate of dissolution of salt with the same particle size and its decrease of impedance. These results were apparently caused by water content of the gel, which affected solubility of the salt and osmosis of the salt in differences of internal structure of gels.

The solubility of four groups of salt with diameters of 1180-1400, 600-710, 300-600, and 150-212 μm in NaCl solution was measured (Figure 10). The ratio of salt dissolution became smaller along with its particle size. We assessed the correlation between solubility and impedance value using salt of 600-710 μm diameter. We showed the NaCl concentrations (%) of salt with diameter of 600-710 μm in Figures 10 and its impedance value from Figures 4, 6 and 7 (Figure 11). Figure 11 presents an inverse correlation between salt solubility in solution and the impedance value. Consequently, the relations of both parameters were extremely high. Measurements of impedance values enable evaluation of the solubility of salts on food surfaces.

In conclusion, the impedance measurements by LCR meter were useful to monitor salt solubility on food surfaces in a non-destructive and real-time manner.

Figure 9 Impedance values of salts with particle diameters between 150-212 μm on five gel surfaces.

Figure 10 Solubility of salts with various particle diameters in 28% NaCl (w/v) solution.

Figure 11 Relations between impedance values and solubility of salt with diameter at 600-710 μm in NaCl concentrations.

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