Note

Effect of Weak Electrolyzed Water on the Properties of Bread

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Weak electrolyzed water obtained by electrolysis of tap water has various physicochemical properties. This study investigated the effects of weak electrolyzed water on making bread. Sensory evaluation revealed that when weak electrolyzed anode water was used, the breadcrumb had a higher elasticity than that made with tap water, and when weak electrolyzed cathode water was used, the breadcrumb was softer than that made with tap water. This finding suggests that the use of electrolyzed anode water would produce bread of higher elasticity in the acid soluble large molecular weight gluten sub-unit which participates in the formation of a more soluble gluten-matrix. It was suggested that the use of electrolyzed cathode water would produce soft bread in that the gluten-matrix would become fragile and that the chemical gelatinization of wheat starch would be accelerated by the alkali.

Keywords: electrolyzed water, bread, gluten-matrix, gelatinization

In the food industry, water is considered as an important raw material. Various methods of water treatment have been developed and utilized (Isobe, 1995; 1999), and various kinds of water have come into use in food processing. Particularly, electrolyzed water obtained by electrolysis of feed water (including tap water and a solution of salt) has various physicochemical properties that feed water alone does not have in respect to pH, mineral content, oxidation-reduction potential (ORP), dissolved oxygen content, etc. (Iwamoto, 1993; Hotta & Suzuki, 1999). There is a strong possibility that these property functions are effective in food processing.

At present, the main type of electrolyzed water utilizing membrane that separates the positive and negative electrodes is called strong electrolyzed water. Strong electrolyzed water is added to electrolytes such as sodium chloride (NaCl) before electrolysis. After electrolysis, strong electrolyzed anode water is obtained from the anode side and strong electrolyzed cathode water from the cathode side. For the action of hypochlorous acid produced by electrolysis of NaCl solution, strong electrolyzed anode water is used for the sterilization of products and ingredients (Iwasawa *et al.*, 1993; Yoshida, 1998; Suzuki & Miyashita, 1999). On the other hand, because of its strong reducing power, strong electrolyzed cathode water is suggested to be effective in scavenging of superoxide anion radical and hydrogen peroxide (Shirahata *et al.*, 1997), and for its antioxidative activity toward polyunsaturated lipids (Miyashita *et al.*, 1999).

There is another type of electrolyzed tap water obtained by utilizing membrane that separates the positive and negative electrodes. Electrolyzed tap water is not added with electrolytes and its properties are considerably different from the above strong electrolyzed water. We refer to this electrolyzed tap water as weak electrolyzed water in this paper. We

previously reported that using weak electrolyzed water (referred to as “electrolyzed water” hereafter) produced by the electrolysis of tap water for cooking rice (Kobayashi *et al.*, 1996), making noodles (Onishi *et al.*, 1997) and preparing *dashi* (*katsubushi* broth; Kobayashi *et al.*, 1997), the quality of the products was higher than in preparations using non-electrolyzed tap water. Thus, when electrolyzed cathode water was used to cook rice from aged grains, the final product softened and its stickiness increased so that its texture was improved. Electrolyzed anode water used in making noodles increased the elasticity of the boiled noodles, and when electrolyzed cathode water was used to prepare *dashi*, the extraction of inosine 5'-monophosphate (IMP) and glutamic acid was increased.

This study investigated the effects of electrolyzed water (anode water and cathode water) used in making bread, the consumption of which has increased in recent years and which is fast becoming a staple food of the Japanese. This study looked at the possibility of using electrolyzed water for food processing and, as in our previous study (Onishi *et al.*, 1997), the water we used was not experimental water like distilled water, but was tap water utilized in actual food processing.

Materials and Methods

Materials The wheat flour used in this study was commercial hard wheat type (“Supercamera” from Nisshin Flour Milling Co., Tokyo). Its protein, ash and water contents were 12.3%, 0.35% and 14.5%, respectively. Other ingredients were active dry yeast for baking (Oriental Yeast Co., Tokyo), salt (Japan Tobacco Inc., Tokyo), shortening (Snow Brand Milk Products Co., Tokyo), sugar (Nippon Beat Sugar Mfg., Co., Tokyo) and skim milk powder (Snow Brand Milk Products Co.).

Water Non-electrolyzed tap water from Matsue City

(pH 6.75, referred to as "tap water" hereafter) was used in this study. Using an electrolyzing device, two kinds of electrolyzed water were obtained from the tap water. The conditions for the electrolysis were: device, model HOX-40A, Hoshizaki Electric Co., Nagoya; electrolytic voltage, 50.0 V; electrolytic current 2.0 A; temperature of feed water, 21.8°C. Electrolyzed water obtained from a positive electrolytic cell (pH 3.20, referred to as "anode water" hereafter) and electrolyzed water obtained from a negative electrolytic cell (pH 10.30, "cathode water") was used. Since this study sought to confirm the effectiveness of anode water and cathode water in breadmaking, the pH values of these electrolyzed waters were set to the minimum and maximum pH available by the above electrolyzing device.

Prior to the main study, the specific characters of the above water were measured. ORP was measured with an ORP meter (D-23, Horiba, Kyoto), residual chlorine was measured by the *O*-tolidine method (residual chlorine meter, Shibata Scientific Technology, Tokyo), electric conductivity was measured with an electric conductivity meter (ES-14, Horiba, Kyoto), dissolved oxygen (DO) was measured with a dissolved oxygen meter (D-25, Horiba), cation (chloride ion and nitrate ion) concentration was measured by an ion chromatograph (Model CRB, Dionex) and anion (potassium, calcium, magnesium and sodium) concentration was measured by an atomic absorption spectrometer (Model AA-890, Jarrell Asc).

Breadmaking Bread was prepared using automatic home breadmakers (model SD-BT 50, Matsushita Electronic Co., Osaka). The bread was made by the straight dough method wherein all materials were mixed simultaneously without the use of food additives such as yeast foods and emulsifiers, in order to elucidate the direct effect of the applied waters on the breadmaking materials. The ingredients used in the bread were 280 g wheat flour, 5 g salt, 10 g sugar, 5 g skim milk powder, 5 g shortening and 4.2 g active dry yeast. Water was added in an amount 70% the weight of the above flour. The breadmaking process included 30-min mixing, 15-min kneading, 15-min pre-fermentation, 2-h primary and secondary fermentation and 45-min baking (total 3.75 h). After baking and cooling at 20°C for 1 h, the bread was subjected to sensory evaluation and to various measurements.

Scanning electron microscope observation After secondary fermentation, part of the dough from the center was collected and immediately frozen in liquid nitrogen and lyophilized. According to the method of Nihei *et al.* (1990), the lyophilized sample was fixed with a 4% solution of glutaraldehyde and its starch was partially hydrolyzed by immersing it in a 0.1% solution of α -amylase (10×10^4 DUN/g, Nagase Biochemicals Co., Kyoto) at 35°C for 2 days. The hydrolyzed samples were washed with distilled water, lyophilized and then each section was observed by a scanning electron microscope (model S-4500, Hitachi) at an acceleration voltage of 5 kV and of 1000 fold magnification.

Color Color was measured with a color difference meter (model CR-300, Minolta Co., Osaka). The colors of the crusts and crumbs of bread samples were measured based on $L^*a^*b^*$ values belonging to the CIE colorimetric system using the conditions for the measurement based upon JIS Z 8729. From the measurements obtained, the whiteness values

were calculated using Hunter's whiteness formula (Uchida & Hukuda, 1988).

Specific volume Specific volume of each bread loaf was measured by the seed substitution method (Griswold, 1962).

Measurement of bread texture A creep meter (model RE 2-3305, Yamaden Co, Tokyo) was used to determine the maximum force and cohesiveness of the breadcrumbs. The conditions for measurement of the maximum force were: sample size, 30×20×20 mm; plungers, wedge form (1×20 mm); measurement strain rate, 80%; compression speed, 5 mm/s. The conditions for the measurement of cohesiveness were: sample size, 20×20×20 mm, plunger, circular form (40 mm in diameter); measurement strain rate, 80%; compression speed, 5 mm/s. The compression test was conducted twice and the cohesiveness was expressed as the rate of peak areas measured after the first compression and the second compression (the peak area of the first compression/the peak area of the second compression).

Degree of gelatinization A mid-portion of the breadcrumbs was collected immediately after baking finely ground in cold ethanol and cold acetone to give a dehydrated powder sample. Degree of gelatinization of the resulting sample was measured by the β -amylase-pullulanase method (Kainuma *et al.*, 1981).

Sensory evaluation The evaluation was carried out by panels composed of 50 male and female students (20–25 years old) of Shimane University. Seven factors of breadcrumb samples (whiteness, hardness, springiness, adhesiveness, flavor, taste and overall judgement) were evaluated by a rating scale method using a seven-grade scale wherein the crumb samples were scored from +3 to −3. Bread used with tap water (non-electrolyzed water) was prepared and used as a reference (0) for sensory evaluation.

Statistical analysis Comparison of two means were made by Student's *t*-test (Fisher, 1958).

Results and Discussion

The specific character of water in this study Before the main study, the specific characteristics of water were measured (Table 1). Compared with the raw tap water, anode water has low pH, high ORP, high DO and high amount of cation such as chlorine ion and nitrate ion. On the contrary, compared with tap water, cathode water has high pH, low ORP, low DO and high amounts of anions like potassium, sodium, calcium and magnesium. Both electrolyzed waters (anode water and cathode water) have high electric conductivity and low residual chlorine. These results confirmed that anode water and cathode water obtained by electrolysis of tap water have various physicochemical properties that tap water does not have. The experiments of making bread with this electrolyzed water and tap water were therefore done.

The properties of breadmaking with electrolyzed water First, the development of gluten-matrix in bread dough was compared using both electrolyzed waters and tap water by observing the structure of the dough immediately after completion of the secondary fermentation (Fig. 1). In the dough made with anode water, the gluten-matrix developed well to form thin membranes and coated starch granules compared with the dough using tap water. In the dough made

Table 1. The specific characteristics of water.

Index	Electrolyzed ^{a)}		Non-electrolyzed
	Anode water	Cathode water	Tap water
pH	2.85 ± 0.7	10.35 ± 0.12	6.75 ± 0.31
ORP (mV)	766 ± 14	-745 ± 16	401 ± 14
Dissolved oxygen (mg/l)	14.1 ± 0.14	6.3 ± 0.04	7.2 ± 0.04
Electric conductivity (ms/cm)	0.31 ± 0.01	0.12 ± 0.00	0.08 ± 0.03
Residual chlorine (mg/l) ^{b)}	0.2 ± 0.0	N.D.	0.3 ± 0.0
Ion concentration (mg/l) ^{c)}			
Cl ⁻	18.72 ± 1.2	3.6 ± 0.2	8.5 ± 0.1
NO ₃ ⁻	3.81 ± 0.3	0.77 ± 0.2	1.32 ± 0.3
Na ⁺	3.91 ± 0.3	10.5 ± 0.0	7.68 ± 0.3
K ⁺	0.5 ± 0.0	1.4 ± 0.0	0.9 ± 0.2
Ca ²⁺	1.7 ± 0.3	5.3 ± 0.0	3.9 ± 0.1
Mg ²⁺	0.4 ± 0.3	0.7 ± 0.1	1.1 ± 0.0

^{a)}Using an electrolyzing device, two kinds of electrolyzed water (anode water and cathode water) were obtained from the electrolysis of tap water. The conditions for the electrolysis tap water were; device, Hox-40A, Hoshizaki Electric CO., electrolytic voltage, 50.0 V, electrolytic current 20.0A, temperature of feed water, 21.8°C.

^{b)}Residual chlorine was measured by *O*-tolidine method.

^{c)}Cation (Cl⁻ and NO₃⁻ was measured by ion chromatography and anion (Na⁺, K⁺, Ca²⁺ and Mg²⁺) was measured by atomic absorption spectrometry, respectively.

with cathode water, however, an intermittent and fragile gluten-matrix was generated compared with the dough made with tap water. These results suggest that the use of anode water improved the dissolution and dispersion of proteins responsible for the formation of gluten, so that the gluten-matrix developed sufficiently. The results implied that bread made with electrolyzed water is different from that made with tap water. Accordingly, the above breads made with both types of electrolyzed water (anode water and cathode water) and that with tap water were compared and their color, specific volume, texturometric properties, degree of gelatinization of the breadcrumbs and sensory evaluation noted.

The color of the bread crust and the breadcrumbs were evaluated (Table 2). Compared with the bread crust using tap water, the one made with anode water showed a significantly higher $+a^*$ value indicating a red color and $+b^*$ value indicating a yellow color, and that made with cathode water showed a significantly higher $+a^*$ value. These facts showed that when electrolyzed water was used in breadmaking, the bread crust had a higher color of orange than when tap water was used. The amino-carbonyl reaction participates in the crust coloration; therefore, it is presumed that certain amounts of amino groups and carbonyl groups as reaction species increase during the kneading and fermentation of the dough.

The whiteness of breadcrumbs, however, revealed a subdued white done when compared with bread made with tap water. Contrary to these results, subsequent sensory evaluation showed that the bread made using electrolyzed water had a higher whiteness than that made with tap water. This difference is believed to result from the difference in whiteness recognized by the panel and that measured with the measuring instrument. When the color difference (ΔE^*ab) between the two breads was calculated, both the crust and crumb of these breads showed a color difference much greater than the recognition threshold ($\Delta E^*ab=2.5$; Nayatani, 1993) of a

Fig. 1 Scanning electron micrograms of bread dough. A, made with electrolyzed acidic water. B, made with non-electrolyzed neutral water. C, made with electrolyzed basic water.

skilled panel. Therefore, even consumers are believed able to distinguish the color difference.

Next, the specific volume of bread, the texturometric properties of crumbs and degree of gelatinization were measured (Table 3). Although no significant difference in the specific volume was observed between the bread made with tap water and that made with electrolyzed water, bread made with cathode water had a tendency to have a somewhat greater volume and that made with anode water a somewhat smaller volume. This suggests that, because of the good formation of gluten in anode water, the dough does not

Table 2. Color index of the bread made with different water.

Index	Electrolyzed		Non-electrolyzed
	Anode water	Cathode water	Tap water ^{a)}
Crust			
	av±s.e.	av±s.e.	av±s.e.
<i>L</i> *	48.5±0.5	47.6±0.6	46.5±1.1
<i>a</i> *	+14.9±0.2***	+14.5±0.2**	+13.5±0.3
<i>b</i> *	+29.0±0.4*	+28.2±0.4	+26.5±0.2
$\Delta E^* ab^{b)}$	5.67±0.77	4.25±0.65	—
Crumb			
	av±s.e.	av±s.e.	av±s.e.
<i>L</i> *	72.4±0.8*	74.4±0.6*	76.7±0.7
<i>a</i> *	-2.49±0.1	-2.53±0.1	-2.53±0.1
<i>b</i> *	+12.5±0.3	+11.6±0.3	+12.2±0.3
$\Delta E^* ab^{b)}$	3.29±0.58	3.72±0.58	—
Whiteness ^{c)}	71.2±0.8*	72.0±0.7*	73.6±0.7

^{a)}Used as a reference for statistical analysis. *, ** and *** mean significance at 5, 1 and 0.1% levels, respectively, between the datum of the reference (tap water) and that of the samples (anode water and cathode water).

^{b)}Color difference between the values of reference (tap water) and that of the samples (anode water and cathode water).

$$\Delta E^* ab = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

^{c)}Calculated using Hunter's whiteness formula.

$$\text{Whiteness} = 100 - [(100 - L^*)^2 + (a^{*2} + b^{*2})]^{1/2}$$

Table 3. Effects of water used in breadmaking on properties of breadcrumbs.

Property	Electrolyzed		Non-electrolyzed
	Anode water	Cathode water	Tap water ^{a)}
Specific volume of the bread loaf (cm ³)	av±s.e. 1512±65	av±s.e. 1537±51	av±s.e. 1523±49
Texturometric			
Maximum force of crumb (gf)	368±37	259±22***	349±26
Cohesiveness of crumb	0.84±0.01***	0.79±0.01	0.80±0.01
Degree of gelatinization (%)	82.0	84.2	82.1

^{a)}Used as reference for statistical analysis. ***means significance at 0.1% levels, between the datum of the reference (tap water) and that of the sample (anode water and cathode water).

spread as easily and its swelling is suppressed, whereas because of the poor formation of gluten in cathode water, the dough spreads well and its swelling is enhanced.

With respect to food with a lean taste such as bread, the physical properties of its crumbs are important factors that determine consumer preference. Accordingly, the maximum force of the breadcrumb was measured as an indication of hardness and the springiness as an indication of cohesiveness. Compared with the bread made with tap water, that made with cathode water had a significantly decreased maximum force when the crumb softened. Bread made with anode water did not show a significant difference in maximum force from that made with tap water. It was shown by determining the springiness of bread that bread made with anode water had a significantly increased springiness and increased cohesiveness of the crumb. In the case using cathode water, no significant difference in springiness was observed. It is presumed from these results that, when anode or cathode water is used in breadmaking, the dough's properties of gluten formation, which influence the physical properties of the crumb, change to produce a bread different from that prepared using tap water.

Table 4. Sensory scores of breadcrumbs made with electrolyzed water.^{a)}

Parameter	Electrolyzed	
	Anode water	Cathode water
	av±s.e.	av±s.e.
Whiteness ^{b)}	0.14±0.11	0.26±0.10*
Hardness ^{c)}	0.42±0.16*	0.96±0.17***
Springiness ^{d)}	0.65±0.15***	0.38±0.15*
Adhesiveness ^{e)}	0.34±0.12*	0.17±0.11
Flavor ^{f)}	0.18±0.10	0.33±0.10**
Taste ^{g)}	0.67±0.10***	0.42±0.12**
Overall judgement ^{h)}	0.66±0.13***	0.76±0.10***

^{a)}The bread made with tap water (non-electrolyzed) was prepared and used as a reference (0) for sensory evaluation. *, ** and *** mean significance at 5, 1, and 0.1% levels, respectively, between the datum of the reference (tap water) and that of the samples (anode water and cathode water).

^{b)}5, very white. —5, not white.

^{c)}5, very soft; —5, very hard.

^{d)}5, very springy; —5 not springy.

^{e)}5, very adhesive; —5 not adhesive.

^{f)}5, very good; —5 very poor.

^{g)}5, very good; —5 very poor.

^{h)}5, very favorable; —5, very unfavorable.

During the baking process, wheat starch absorbs free water and water that hydrated the gluten in dough and causes it to gelatinize. Consequently, the gluten-matrix loses its fluidity and is thermally denatured to fix the texture of the bread (Tanaka & Matsumoto, 1995). During this process, the starch gelatinizes, swells, increasing its viscosity and filling up gaps in the gluten-matrix while enveloping forms. It is contemplated that not only gluten-matrix but also the gelatinization property of starch affects the physical properties of crumbs. Therefore, the degree of gelatinization of breadcrumbs immediately after baking was measured as an indication of the gelatinization property of the starch. When cathode water was used, the degree of gelatinization was higher than that with tap water; this indicated that the high pH of cathode water caused the chemical gelatinization of wheat starch to proceed. There was no difference, however, in the degree of gelatinization between anode water and tap water. Thus, the softening of breadcrumbs made with cathode water was considered to be influence not only by the weakness of the gluten-matrix but also by a high gelatinization that increased the water of hydration of starch and suppressed the loss of water during baking.

Sensory evaluation of the crumbs from bread made with anode water and cathode water was done using tap water as a reference sample (Table 4). When electrolyzed water was used for breadmaking, each of the properties of the obtained bread showed a positive score value, and these loaves were observed to have sensorial superior qualities compared with bread using tap water. The breadcrumbs using anode water were evaluated to have rich in cohesiveness, while the crumbs using cathode water were found high in softness. The overall judgment was indicated that the crumbs using electrolyzed water were preferable, and so it can be concluded that these changes are positive from the point of view of taste. The results of sensory evaluation showed that electrolyzed water used in breadmaking resulted in a product of higher quality than that using tap water.

We therefore determined electrolyzed water in breadmaking served to modify the bread properties. Electrolyzed water has various physicochemical properties that tap water does not have, and is presumed these properties influence bread materials and components such as yeast, wheat protein and wheat starch during the breadmaking process. Thus pH is affected by wheat protein extraction and gelatinization of wheat starch, and ORP is affected by the disulfide bonds of wheat protein. Our next study will be on the effect of electrolyzed water on bread materials and components during breadmaking, and will also the mechanism by which bread quality is determined.

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