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An Approach to the Evaluation of the Physical Quality of Rice Cakes

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It is known that the deterioration of rice cakes largely depends on the temperature of the environment after manufacture of the rice cakes. The reason for this is that the physical state of water in the rice cakes is changed by the application of heat, and the restoration properties of the rice cakes are eventually lost. This study was made to numerically express the degree of deterioration of rice cakes based on the relationship between the temperature and the conductivity of the rice cakes. Four types of rice cake samples with different degrees of deterioration were prepared by repeating a heat treatment of 60℃ for one hour, using a rice cake immediately after manufacture. The conductivities of these rice cake samples were measured as they were frozen by decreasing the temperature from 0℃. Measurement of the conductivity of the rice cake samples confirmed that the temperature at which the conductivity drops sharply, due to freezing of the water in the rice cake, is related to the degree of deterioration. The deterioration is caused by the movement of water in the rice cakes when the moisture content of the rice cakes is controlled within the range of 41.5 to 44.0% at manufacture. This temperature can be used as an index to indicate the degree of deterioration of rice cakes. This fact was supported by DSC and DTA analyses, and the data for the solubility of starch in hydrochloric acid. In addition, it has been judged from a taste test of rice cakes manufactured without using any additives that there is a quality limit to the rice cake samples which were prepared by multiple heat treatments (three times). The conductivity drop temperature of the above-mentioned sample was -6.0 ± 0.5℃.

Introduction

The quality evaluation of rice cakes is very complicated[1] because the factors that relate to quality include the extensibility, elasticity, texture, luster and color, and also the taste and smell of the rice cakes.

Generally, rice cakes prepared by pounding during the cold winter season are very tasty, and even when such rice cakes are cooled and become hard, they can be restored to the original state by boiling or toasting. On the other hand, it is usually well known that rice cakes pounded in the summer are eaten while soft because they do not have the same restoration properties as the rice cakes pounded in the winter. The restoration properties of the rice cakes are such that the rice cakes can be restored to the original state by boiling or toasting when they become hard.

In view of these facts, it is considered that the restoration properties of rice cakes are significantly influenced not only by the cooling conditions immediately after the rice cakes are pounded, but also by the temperature of the environment after such preparation of the rice cakes.

With the recent implementation of regulations providing an indication of the date of minimum durability for foods[2], it has become important to understand the effects of preservation on the quality of the rice cakes.

One method of evaluating the quality of foods is by measuring their electrical properties[3)4)]. This approach has been put into practice in the fields of fruit juice, and vegetables and fruits[5)6)]. Many papers deal with the above-mentioned subject, for instance, the determination of the organic acid content[7)~9)], and the sugar content[10)] of citrus juice based on conductometry. In addition, the measurement of the resistivity and impedance of foods ; can provide an indication of the quality of tomatoes[11)] ; determine the moisture content in raisins[12)] ; provide a quantitative measurement of bruise and pressure injury in apples[13)] ; allow judgment of the ripeness of macadamia nut[14)] ; identify irradiated potatoes[15)16)] ; and separate of living and dead corn kernels without germination[17)]. However, there have been no studies on analyzing the movement of water in processed starch foodstuffs by measuring the conductivity with respect to temperatures around the freezing point.

In the present study, we have considered that the localized movement and distribution of water within the rice cake is related to the heat environment that the rice cake is exposed to after manufacture. Therefore, in this paper by preparing four types of rice cake samples exposed to different heat treatment conditions, we tried to assess the effects of the water movement in the rice cakes on their restoration properties by measuring the changes in the conductivity of the rice cakes and to obtain standard values for evaluating rice cakes.

Materials and Methods

Preparation of reference samples

Reference samples of rice cakes were prepared as follows : Glutinous rice, which is generally used, was washed well with water, steamed by a conventional method, pounded with a pestle 120 times, made into a flat cake, rapidly cooled to 2℃ over a period of 4 hours, vacuum-packaged in a plastic bag and aseptically stored in a refrigerator at 2℃ for 48 hours. Thus, standard reference samples without heat treatment were prepared. These are referred to as non-heat-treated standard reference samples. One-time heat treated reference samples were obtained by subjecting the non-heat-treated reference samples to heating at 60℃ for one hour and subsequently allowing the samples to stand at room temperature. By repeating this heat treatment two or three times, 2-time heat treated reference samples and 3-time heat treated reference samples were prepared, respectively. As a result, four types of rice cake samples with different degrees of heat treatment were prepared.

In order to examine the influence of the moisture content on the conductivity of rice cakes, non-heat-treated moisture-controlled samples and 3-time heat treated moisture-controlled samples were prepared from the steamed glutinous rice which had different moisture contents. The moisture content of each reference sample was controlled within the range of 44% to 40% by rapidly drying the steamed glutinous rice by applying hot air and pounding with a pestle 120 times.

Method of measurement

The taste test was a blind test, in which the four types of rice cake samples were provided at random to each of eight panelists, without previously giving information about the identification of the rice cake samples to the panelists. Then, the four types of rice cake samples were graded A, B, C and D in order of merit by the panelists according to the extensibility, elasticity, flavor, and overall judgment.

The conductivities of the rice cake samples were measured with a commercially available tester (Trademark "3520LCR Hi-Tester", made by Hioki Denki Co., Ltd.) using the following method : A 40 mm×32 mm×15 mm rectangular parallelepiped was cut from each rice cake

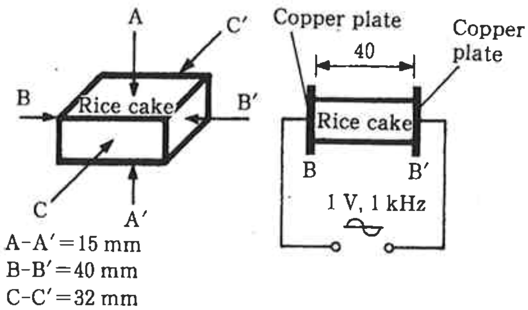

Fig. 1 Method of measurements

sample, as shown in Fig. 1, and two copper plates were attached to the opposite faces B and B′ of the rectangular parallelepiped. The faces were separated by 40 mm and each face B or B′ had an area of 480 mm^2 (32 mm × 15 mm). 1 V AC at 1 kHz was applied across the two copper plates, the impedance was measured, and the conductivity of the rice cake sample was calculated. In this case, an electrically-conductive coating was applied to the copper plates, each of which was brought into contact with the rice cake sample to ensure conduction between the rice cake and the copper plates. This measurement was carried out in a refrigerator while the temperature of the rice cake sample was decreased from 0℃ stepwise by 1℃ every 30 minutes. The temperature at which the conductivity sharply dropped due to the freezing of water in the rice cake was then measured. The measurement was repeated four times using the samples under the same conditions, and the conductivity drop temperature was obtained from the average value.

The state of the water in each of the same reference samples, as used in the above measurement, was analyzed in a low temperature region with a commercially available differential scanning calorimeter (Trademark "SSC580 DS", made by Seiko Electronics Co., Ltd.). The distribution of water in each sample was analyzed in a high temperature region by simultaneous techniques, that is, thermogravimetry (TG) and differential thermal analysis (DTA). The DSC was carried out in accordance with the method of ISHIDA *et al.*[18] and the TG-DTA, in accordance with the method of MOMOTA *et al.*[19].

Furthermore, it has been reported that the amorphous portion of starch decomposes more readily than the crystalline portion and becomes soluble in acid[20,21]. Based on this report, the total weight of starch dissolved from each reference sample in 0.25 N hydrochloric acid was measured by the phenol-sulfuric acid method[22].

Results and Discussion

It has been judged from the results of the taste test as shown in Table 1, and the measurement of the extensibilities of the rice cake samples as shown in Fig. 2, that the extensibility, the elasticity, the flavor, and the preference of the rice cakes decreased with the number of times the heat treatment was repeated. In particular, the flavor of the rice cakes drastically decreased even after just one heat treatment. According to the panelists, the quality of rice cake samples that were heat-treated three times is limited.

Fig. 3 shows the relationship between the temperature and the conductivity of the rice cakes. The results indicate that the point of temperature at which the conductivity begins to sharply decrease (this point of temperature is referred to as the conductivity drop temperature) is elevated from −8.5℃ to −6.0℃ as the movement of water in the rice cakes proceeds due to the application of heat to the rice cakes. It is considered that the amount of free water

Table 1 Judgment of taste test

Sample	Extensibility	Elasticity	Flavor	Overall judgment
Non treated sample (standard)	$A^{++++++++}$	$A^{++++++++}$	$A^{++++++++}$	$A^{++++++++}$
1-time heat-treated sample	$A^{++++++++}$	$A^{+++++++}$ B^{+}	A^{+} B^{+++} C^{++++}	A^{++++++} B^{++}
2-time heat-treated sample	A^{+} $B^{+++++++}$	A^{++} B^{++++++}	B^{+} C^{+++++} D^{++}	B^{+++++} C^{+++}
3-time heat-treated sample	C^{+++++} D^{+++}	C^{++++++} D^{++}	C^{+++} D^{+++++}	C^{++++} D^{++++}

A, excellent ; B, good ; C, passable ; D, poor. $^{+}$, Number of panelists.

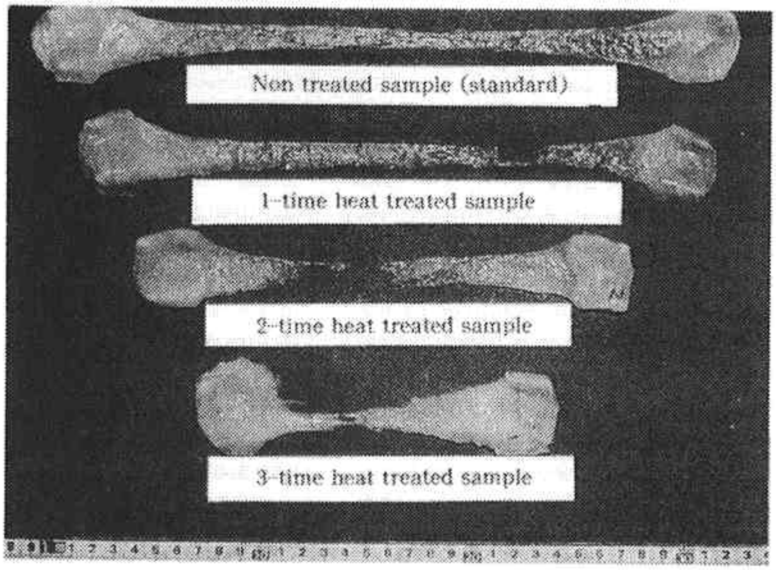

Fig. 2 Changes in the extensibility of rice cakes with repetitive times of heat treatment of 60℃ for 1 hour

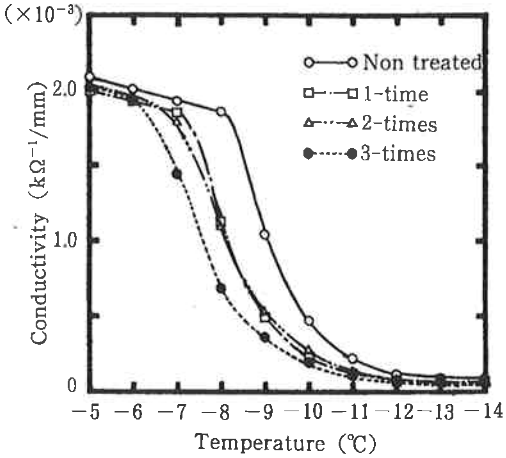

Fig. 3 Conductivity between opposite faces B-B'

in the rice cakes increases and that the conductivity drop temperature is related to the loss of the restoration properties of the rice cakes.

Fig. 4 indicates the effect of the change in the moisture content of the rice cakes on the conductivity drop temperature. As is apparent from the results, when the moisture content of the rice cakes is within the range of 41.5 to 44.0%, the conductivity drop temperature of the rice cakes is not greatly influenced by the moisture content of the rice cakes. It is known that the moisture contents of general types of rice cakes fall within the above-mentioned range.

Figs. 5 and 6 show the results of the DSC and DTA thermograms, respectively. Table 2 indicates the physical state of water in the rice cake samples according to the DSC analysis. The data were obtained by reference to the methods of SHIOTSUBO *et al.*[23] and MUHR *et al.*[24].

The DSC thermograms shown in Fig. 5 confirm that the more times the rice cakes are heat treated, the larger the content of the component with a peak at −3.5℃, which is considered to be free water[18] contained in the rice cakes. In addition, the content of a component with a peak at −8℃, which is considered to be restricted water[18] contained in the rice cakes, conspicuously increases as the movement of water in the rice cakes progresses. It is considered that a part of unfreezable water[18] existing in the rice cakes immediately after the manufacture of the rice cakes becomes restricted water. The DTA thermograms shown in Fig. 6 indicate that the peak temperature of a material absorbing the latent heat, whose main

Table 2 Physical state of water in rice cakes by DSC

Sample	Moisture content (%)	ΔH (J/g*)	Free water (g/g*)	Restricted water (g/g*)	Unfreezable water (g/g*)
Non treated sample (standard)	42.7	112.2	0.260	0.075	0.665
1-time heat-treated sample	42.7	117.1	0.269	0.082	0.649
2-time heat-treated sample	42.7	124.4	0.288	0.084	0.628
3-time heat-treated sample	42.7	136.1	0.316	0.091	0.593

g*, g-dry-rice cake.

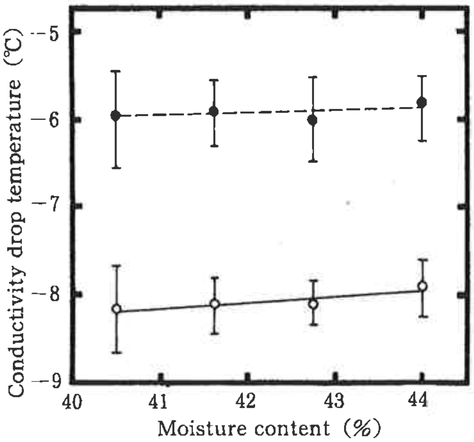

Fig. 4 Effect of moisture content on the conductivity drop temperature

○, non-heat-treated moisture-controlled sample.

●, 3-time heat treated moisture-controlled sample.

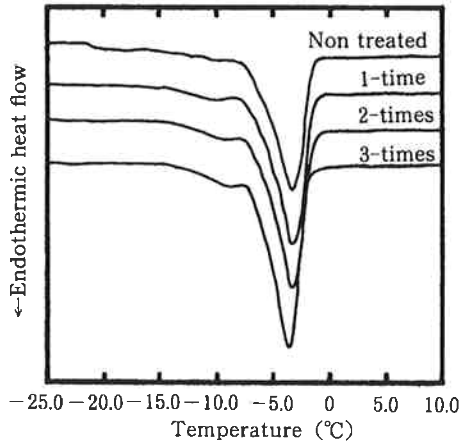

Fig. 5 Changes in DSC thermograms of rice cakes depending on heat treatment

component is considered to be water, decreases from 165℃ to 135℃, and the temperature range of the peak is narrowed as the movement of water in the rice cakes proceeds. This is possibly due to the increasing amount of free water in the rice cakes.

The graph in Fig. 7 shows the change in the solubility of starch in hydrochloric acid depending upon the number of heat treatments given to the rice cake samples. Judging from the graph, the movement of water in the rice cakes promotes the crystallization of starch in the rice cakes, thereby decreasing the solubility of starch in the acid.

It has been confirmed by previously mentioned results that the conductivity drop temperature of rice cakes is closely related to the degree of movement of water in the rice cakes and, consequently, is related to the deterioration of the rice cakes. This is supported by the analyses of DSC and DTA, and the solubility of starch in hydrochloric acid.

Therefore, the conductivity drop temperature is considered usable as a representative value indicating the degree of deterioration of the rice cakes, that is, the loss of the restoration properties, for rice cakes manufactured without using any additives. The conductivity drop temperature for guaranteeing the limit of

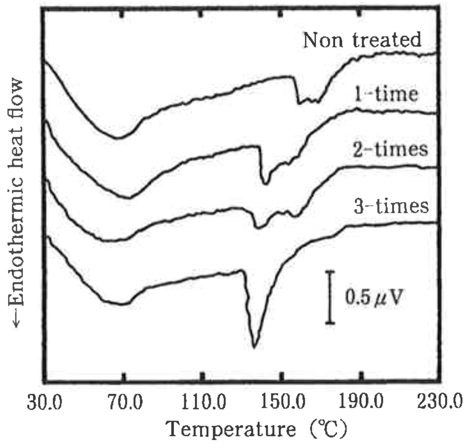

Fig. 6 Changes in DTA thermograms of rice cakes depending on heat treatment

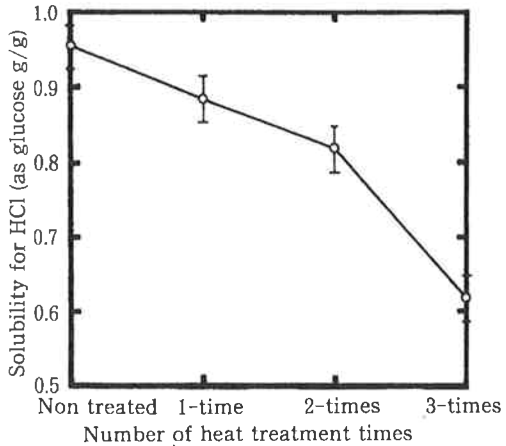

Fig. 7 Solubility of rice cakes in hydrochloric acid depending on heat treatment

the rice cake quality as determined by the taste test was -6.0 ± 0.5℃.

However, the physical state of water in the rice cakes largely depends on how the rice particles have been crushed during manufacture. Therefore, it is necessary to further consider the degree of starch gelatinization in the rice cakes at manufacture and the difference in the mixed states of rice particles in the rice cakes depending upon the manufacturing method, such as a method of pounding with a pestle or a method using a screw or a mixer.

The rice cake reference samples used in the above mentioned experiments were prepared by rapidly cooling to 2℃ over a period of 4 hours after pounding and forming into a flat cake. Further examination of the variability of the cooling conditions of the rice cakes at manufacture is required, because it is believed that the cooling conditions in the preparation of the rice cakes affect the physical state of water in the obtained rice cakes.

Based on the approximation of the physical properties that the 1-time heat treated rice cake reference samples correspond to rice cakes which were allowed to stand at room temperature for about a half year ; the 2-time heat treated reference samples correspond to rice cakes which were allowed to stand at room temperature for one year ; and the 3-time heat treated reference samples correspond to rice cakes which were allowed to stand at room temperature for one and a half years. However, it has been reported[25] that the crystalline state in the rice cakes caused by retrogradation at 50℃ or more is different from that caused by retrogradation at room temperature. In view of this report, further investigation is required. Furthermore, in the case where the rice cakes were stored for a long period of time, consideration must be given to a change in the formation of the rice cakes due to the metabolism of microorganisms and the action of enzymes. Further discussion will be required on these aspects.

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餅の物理的品質評価

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餅の劣化は製造後の熱的環境に大きく依存することが知られている．これは熱により，餅の中の水の存在状態が変化し，復元性が喪失されるものと考えられる．

本研究は餅の熱による劣化度を，温度と導電率との関係により数値化しようとしたものである．製造直後の餅から60℃，1時間の熱処理の繰り返しにより，劣化度の異なる4種類の餅のサンプルを作成し，0℃以下で凍結させながら導電率を測定した．その結果，水分が41.5～44.0%の場合，凍結により導電率の急減する温度点が離水による劣化の程度と密接に関係し，餅の劣化を示す指標となることを確認した．また，離水状態の確認のために行なったDSC，DTA，および酸に対する溶解度もこの傾向を裏付けるものであった．

さらに，無添加で製造された種々の餅について食味テストで判断した結果，3回の熱履歴を受けたサンプルが品質限界と考えられ，このサンプルの導電率の急減開始温度点は，−6.0±0.5℃であった．