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Internal Temperature and Softening Rate of Microwave Cooked Potatoes

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Abstract

The possibility of the prediction of cooking state in microwave cooking was discussed by cooking potatoes at definite temperature by intermittent application of electric current. The increase in the internal temperature of sample cooked in a microwave oven by a usual method proceeded in the order of the bottom, middle and top of the part of potatoes. The internal temperature reached 100℃ within 1min and 40sec to 3min. The intermittent heating was performed at definite temperature ranging from 67 to 97℃ and the changes in hardness were determined. The softening rate at each definite temperature was calculated from the changes in hardness with time. The rate constant k was given by $k=3.301\times10^{13}\exp(-1.175\times10^{4}/T)$ where T is temperature (°K). The softening ratio was determined by using the internal temperature curves of sample and k at arbitrary cooking time. The softening ratio of calculated value almost agreed with that of experimental one while showing a difference of 13 to 19%. Thus it is suggested that the cooking ratio of microwave cooked potatoes can be approximately predicted with using its softening rate obtained by intermittent heating.

INTRODUCTION

In microwave cooking, a food itself absorbs electric waves and thus generates heat. Accordingly the necessary cooking time widely varies, even in the case of the same food, depending on the weight and the size of the food and various cooking conditions.[1] In addition, the difference in dielectric properties from food to food and the short cooking time make it further difficult to predict the optimum cooking time. It is suggested, therefore, that to set the dial at a somewhat shorter time followed by optionally extending the cooking time in such a manner as to cook the food in a desired state.[2]

A number of analyses on the heating properties of foods have been made in order to theoretically clarify the complicated cooking mechanism in microwave cooking.[3−6] However none of these studies directly relates to the prediction of the cooking state.

It is an object of this study to discuss the possibility of the prediction of cooking ratio of food with the use of kinetic methods whereby we have succeeded in the prediction of the optimum time for boiling potatoes.[7]

As for microwave cooking, the cooking rate of a food based on the changes in the internal temperature of sample with heating in a non-stationary system has been reported.[8],[9] But no study has been found regarding heating in a stationary system which is commonly used as a high reliable method in kinetic analyses.

In this report, potatoes were heated at definite temperatures by intermittently applying electric current to a microwave oven and the cooking rate constants of the potatoes at various temperatures were determined so as to calculate the cooking rate. Softening ratio was employed as an indicator of a cooking state of potatoes.

MATERIALS AND METHOD

1. Samples

Potatoes produced in a single farm in Shihoro, Hokkaido (Danshaku, each weighing 150 to 200g) were used. These potatoes were first stored at 10℃ and then 20℃ one week before the experiment. The potatoes were cut into 3cm cubes and those of 100g in weight were used as a sample for microwave cooking.

2. Microwave cooking

The above sample was cooked in two ways, usual heating and intermittent heating, by using a microwave oven (Toshiba ER540, output: 500W).

1) Usual heating

A sample was evenly placed on a heat-resisting glass dish (internal diameter: 21 cm, depth: 1. 5 cm) and covered with a polyethylene film provided with holes (diameter: 1 mm) at intervals of 2 cm. Sample was cooked for 1 to 4. 2 min while rotating the turn table. Immediately after cooking, a copper constantan thermocouple (Rika Kogyo, diameter: 1. 6 mm, stainless-coated) was inserted into the sample and internal temperature at the part of top, middle or bottom of cubed potatoes were measured. The measured point is 0. 5, 1. 5 or 2. 5 cm apart from the center of the upper surface.

2) Intermittent heating

In the usual heating, the internal temperatures of the sample were non-stationary. If the temperature of the sample during microwave cooking can be measured, heating in a stationary system become able to be approximately determined. In order to achieve this object, a hole was made on the rear wall of the microwave oven with an electric drill and a thermocouple was fixed in the oven with fastenings made of the same materials as the inner wall of oven, stainless. The potential of the thermocouple became equal to that of the wall, so that electric resistance was eliminated and any leakage of the electric wave was prevented. It was connected to a recorder and thus the temperature of the sample was measured during microwave cooking. The rotating shaft was removed so as to prevent the rotation of the rotary table during cooking.

The intermittent heating was performed in the following manner. The thermocouple was inserted into the sample and an electric current was applied while externally monitoring the center temperature of the sample. The switch of the electric source was tunrned ON/OFF in such a manner as to maintain a definite temperature ± 1.5℃. That is, the power switch of the oven was manually turned OFF when the temperature reached the definite level +1.5℃, while the switch was manually tunrned ON when the temperature dropped to the definite level −1.5℃. This intermittent heating was repeated and thus the heating at a definite temperature was performed. The definite temperatures were 67, 72, 77, 82, 87, 92 and 97℃, and cooking time ranged from 4 to 120 min. After cooking, the thermocouple was immediately removed and the center part (1 cm^3) of the sample was taken out. After standing it at 20℃ for 1 hour, its hardness was measured.

3. Measurement of hardness

The hardness of the above-mentioned sample was measured with a texturometer (Zenken, GTX-2). The measurement conditions were as follows: plunger, nickel, 50mm in diameter; clearance, 2.5mm; and bite speed, 6 times/min. The test was repeated three times. It was confirmed that the hole on the sample, caused by inserting the thermocouple, never affected the hardness determined with the texturometer.

RESULTS AND DISCUSSION

1. Changes in internal temperature of potatoes during microwave cooking

100 g of potato cubes (3 cm) were cooked by microwave usual heating and the temperatures at the part of top, middle and bottom of the sample were measured (Fig. 1). Differences in temperature among the parts were observed immediately after the initiation of the cooking.

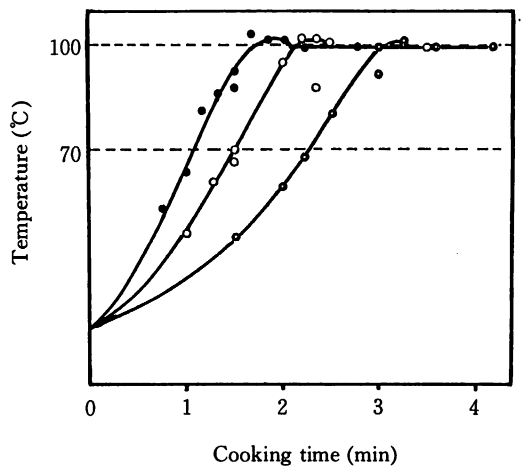

Fig. 1. Changes in the internal temperature of potatoes during microwave cooking as a function of part potatoes.
◎ Top ○ Middle ● Bottom

Temperature at the bottom part was most rapidly went up, followed by middle. The temperature rise at the top part was considerably slow. These results agreed with the progress in the softening reported in our previous paper.[1] The part of bottom required 1 min and 40 sec to reach 100 ℃, while top required slightly more than 3 min.

That the internal temperature of potatoes exceeded 100 ℃ agreed with the result by Kubota et al.[9] It seemed a characteristic of microwave cooking.

2. Softening rate of potatoes in microwave cooking

Akahoshi et al.[10] described that the internal temperature of a sample could be easily adjusted to a definite level in microwave cooking since microwave electric power could be arbitrarily controlled. Roussy et al.[11] maintained the temperature of EPDM rubber particles at 150 ℃ by using a thermocouple under computer-controlled electric power. In this study, in order to performed cooking at a definite temperature, we employed a procedure of the intermittent heating by the manual operation.

Fig. 2 shows changes in hardness during intermittent heating at definite temperatures in

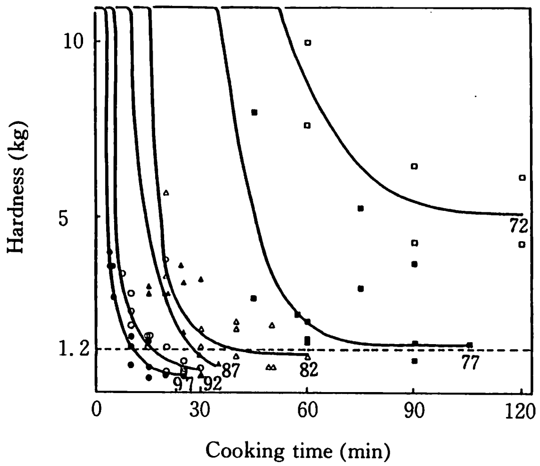

Fig. 2. Hardness of microwave cooked potatoes at various cooking temperatures.
● 97℃, ○ 92℃, ▲ 87℃, △ 82℃, ■ 77℃, □ 72℃,

microwave cooking. Similar to the conventional cooking by heat conduction, the softening rate increased with an increase in the cooking temperature. When the cooking temperature was lower than 77 ℃, the optimum cooking state of 1.2 kg[1] could not be achieved even by cooking for 100 min or longer. At 67 ℃, no softening occurred after cooking for 120 min. In the conventional cooking, the suitable cooking state could not be obtained at 85 ℃, whereas it was obtained at 82 ℃ in microwave cooking.[7] It suggests that the microwave cooking would cause the softening of potatoes at a lower temperature.

Next, the softening ratio was analyzed according to the method used in the case of boiled potatoes. The softening ratio, x $(0 \leqq x \leqq 1)$ was defined as follows.

$$x = \left| (y_0 - y)/(y_0 - y_e) \right| \tag{1}$$

Here, y_0 is initial hardness, y_e hardness at equilibrium and y measured hardness.

y_0 is reffered to as 11. 0 kg, the hardness of raw potatoes, and y_e is reffered to as 0. 75 kg[1], the equilibrium hardness of usually heated potatoes in microwave oven. y is the value shown in Fig. 2. In the optimum cooking state, the softening ratio x is 0. 96 since y is 1. 2 kg.

Supposing that the softening ratio x of experimental value can be approximated by the following first-order kinetics (2), the equation (3) was obtained.

$$dx/d\theta = k(1-x) \qquad (2)$$

$$\ln(1-x) = -k\theta \qquad (3)$$

Here, θ is cooking time (min) and k softening rate constant (min^{-}).

When $(1-x)$ was plotted against θ by using the experimental values of x given by the above equation (1), a linear relation was achieved at every temperature showing softening (Fig.3).

The value of k at each definite temperature was calculated and plotted employing Arrhenius equation (Fig. 4). As a result, a linear graph was obtained at a high correlation. Therefore it is considered that the rate constant in the softening of potatoes in microwave cooking would follow Arrhenius equation (4).

$$\ln k = C - E/RT \qquad (4)$$

Here, C is a constant, T absolute temperature (°K), R gas constant (8. 314 J/mol °K) and E activation energy (J/mol).

Based on this line, activation energy of 97. 7 kJ/mol is obtained. This value is close to the known date of potatoes. It falls within the range of those determined in microwave cooking (41. 0 or 101[8] and 76. 5[9] kJ/mol) and is slightly lower than those in boiling (123,[12] 124,[13] 145[7] and 244[14] kJ/mol). Thus rate constant k was calculated as follows.

$$k = 3.301 \times 10^{13} \exp(-1.175 \times 10^4/T) \qquad (5)$$

The values of k calculated at 80 to 100 ℃ are somewhat high, compared with those determined in boiling. This is seemingly caused by a proceeding of softening due to the characteristic molecular vibration[9] in microwave cooking.

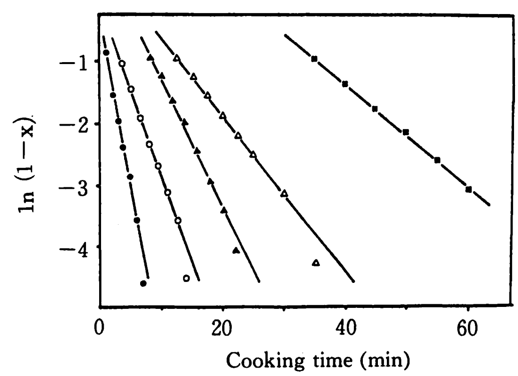

Fig. 3. Softening curves of microwave cooked potatoes at various temperatures.
● 97℃ ○ 92℃ ▲ 87℃ △ 82℃ ■ 77℃

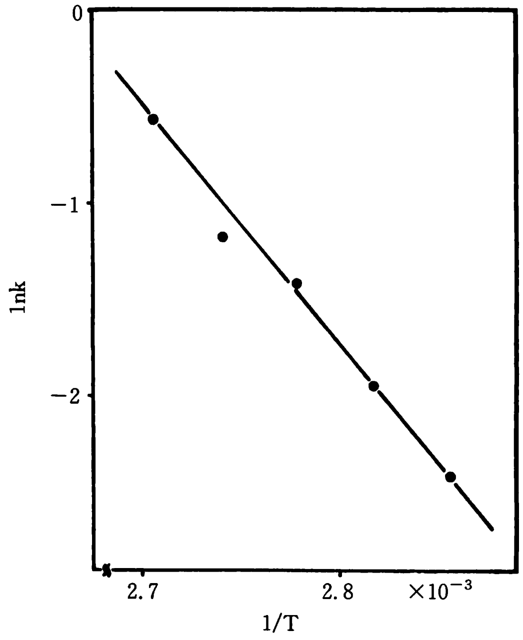

Fig. 4. Arrhenius plot for the softening of potatoes by microwave cooking.

Thus it was confirmed that the softening of potatoes in microwave cooking would depend on temperature and rate constant was determined. Then a method for practically calculating the softening ratio of potatoes by using the internal temperature curves which have been obtained is going to be derived.

3. Calculation of softening ratio from internal temperature

The above equation (2) shows the softening rate. The equation (3), which has been obtained by integrating the equation (2), may be transformed as follows.

$$x = 1 - e^{-k\theta} \qquad (6)$$

The equation (6) shows the softening ratio at a certain point after cooking for θ min at a definite temperature (T).

The internal temperature at arbitrary cooking time θ was expressed as rate constant k, and then $k\theta$ was calculated by using a method of figure integral in accordance with the trapezoid formula. The $k\theta$ thus obtained was substituted into the equation (6) and thus softening ratio x of calculated value can be given.

Here, the temperature of the sample scarcely decreases until it is taken out from the dish. Subsequently, the cooking of the sample proceeds until the temperature drops to 70 ℃. This is called as carry-over cooking. In microwave cooking where a short cooking time is employed in general, the effect of the carry-over cooking on the final state of cooked food are sometimes unneglected. It was confirmed in this study that the time of carry-over cooking in the achievement of the optimum cooking state corresponded to about 25 to 67 % of the cooking time of the electric current and therefore the carry-over cooking was an important factor in softening of potatoes. Thus the internal temperature at arbitrary standing time during this carry-over cooking period is expressed as rate constant and $k\theta$ in the equation (6) is calculated and added to that of electric current period.

As Fig. 5 shows, the softening ratio curves calculated from the internal temperature is in the order of bottom, middle and top of the potatoes, similar to the internal temperature curves

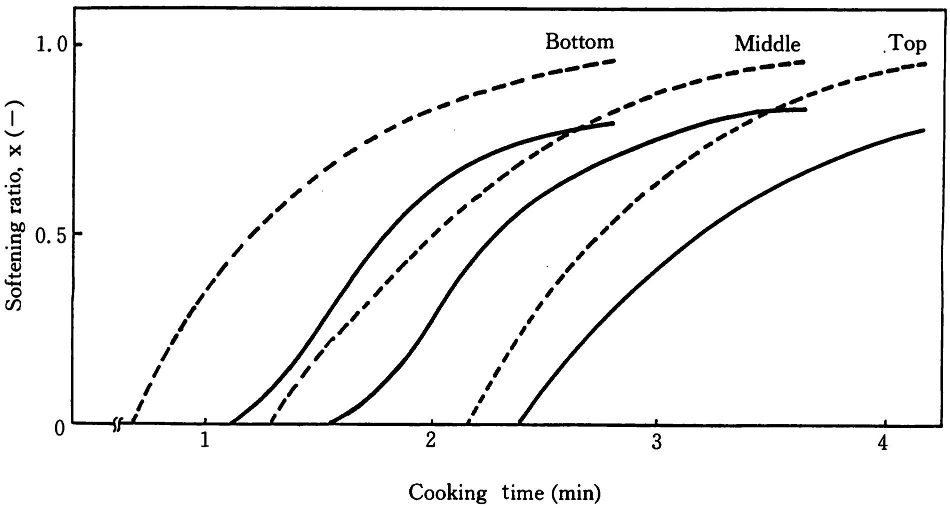

Fig. 5. Comparison between calculated values and experimental values of softening ratio of microwave cooked potatoes.
—— Calculated values, ······ Experimental values

in Fig. 1. The difference at the end of cooking between the calculated softening curves and the experimental ones was 13 to 19 %. The orders of softening as a function of the part of potatoes agreed with each other.

Results of this study suggest that, as respect to the cooking state of microwave cooked potatoes, the process of softening can almost predicted by calculating the softening ratio from the softening rate obtained by the performance of intermittent heating and the interal temperature of sample by usual heating.

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REFERENCES

1) Akinaga, Y., Kasai, M., Hatae, K. and Shimada, A.: J. Home Econ. Jpn., **37**, 955 (1986). (in Japanese)
2) Higo, A.: Denshirenji—Maikuroha Shokuhin Riyou Handobukku, Nippon Kogyo Shinbun Sha, Tokyo, 68 (1987). (in Japanese)
3) Nakazawa, F., Takahashi, J. and Takada, M.: J. Home Econ. Jpn., **40**, 35 (1989). (in Japanese)
4) Shimada, A., Sasaki, K. and Hatae, K.: J. Home Econ. Jpn. **41**, 535 (1990). (in Japanese)
5) Higo, A. and Shimazaki, M.: J. Home Econ. Jpn., **41**, 585 (1990). (in Japanese)
6) Barthakur, N. and Tomar, J.: J. Microwave Power and Electromagnetic Energy, **23**, 39 (1988).
7) Kasai, M. and Shimada, A.: J. Jpn. Soc. Food Sci. Technol., **32**, 360 (1985). (in Japanese)
8) Kubota, K., Araki, H., Suzuki, K. and Esaka, M.: J. Fac. Appl. Biol. Sci., Hiroshima Univ., **25**, 1 (1986).
9) Kubota, K., Kurokawa, M., Suzuki, K. and Esaka, M.: J. Jpn. Soc. Food Sci. Technol., **35**, 10 (1988). (in Japanese)
10) Akahoshi, R. and Matashige, E.: J. Jpn. Soc. Food Sci. Technol., **37**, 581 (1990). (in Japanese)
11) Roussy, G., Mercier, A., Thiébaut, J.—M. and Vaubourg, J.—P.: J.Microwave Power, **20**, 47 (1985).
12) Kubota, K. and Hosaka, H.: J. Jpn. Soc. Food Sci. Technol., **28**, 181 (1981). (in Japanese)
13) Kubota, K., Oshita, K., Hosokawa, Y., Suzuki, K. and Hosaka, H.: J. Fac. Fish. Anim. Husb., Hiroshima Univ., **17**, 97 (1978).
14) Pravisani, C.I., Califano, A. N. and Calvelo, A.: J. Food Sci., **50**, 657 (1985).