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Studies on Simple Convenient Textual Instrument and on Physical Properties of Cooked Soybean

Kiyoshi KUBOTA, Muneharu ESAKA and Kanichi SUZUKI

Faculty of Applied Biological Science, Hiroshima University, Fukuyama

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(Fig.1–8; Table 1–4)

INTRODUCTION

In order to design various cooking apparatuses, it is necessary to measure the cooking rates and establish a cooking rate equation. In previous papers, we have studied the soaking- and cooking-rate equations of starches[1], rice [2-6], beans [7,8], noodles[9-11] and vegetables[12-15]. The determination methods of the empirical and semi-theoretical rate equations and the pseudo mechanisms for the chemical, biological and physical transformations of foods have been studied[2,16,17], and the over-all drying rate equations of foods have been studied[18-24] too by using these determination methods. Studies on the cooking and the drying rate equations have been summarized[25-35] occasionally by the authors.

In order to design and to control automatically various cooking apparatuses, it is necessary to determine the degrees of the cooking of foods by measuring the simple physical properties which can be obtained easily.

The degree of gelatinization of starches has been measured[1] formerly by means of the capillary tube viscometer designed by the authors. This capillary tube viscometer is in fact of a very simple, cheap and convenient type, and has been used for measuring the flow behavior of various liquid foods[36-44]. This viscometer can be used for stain foods[40] and settling suspension foods[44] too just adding a few improvements. These results have been summarized[25,26,45-47]occasionally.

The soaking and cooking rates of the raw rice[2,4], beans[7,8] and noodles[9-11] have been measured by means of a weighing method, because the degree of cooking of low water content foods can be represented as a water soaking phenomenon. However, the cooking rates of high water content foods such as vegetables and so on can not be measured by the weighing method. Therfore, the rheological method[48] and others must be applied for the measurement of these foods. The paralled plate plastometer designed by the authors has been used for measurement of the degree of cooking of soaked rice[3], and the impact-penetration tester designed by the authors has been used for measuring the cooking rates of the vegitable slices[12,13,15],

The impact-penetration tester can be used only for measuring the cooking rates of slice foods. Therefore, we had to make a textural instrument for measuring the rheological properties of agar gels and so on[49]. These methods can be said to be of a very simple, cheap and convenient type, and have been summarized[50].

In order to design various cooking apparatuses, it is necessary to measure the thermal diffusivity which must be used for the cooking of large foods. Therefore we have studied the thermal diffusivity[14,15] of foods and the cooking-rate equation[15] including the thermal diffusivity.

In this study, we made the simple convenient textural instrument which improved the previous one[49,50], and we studied the cooking rate equations of soybean by using the rheological properties, because the measuring studies of the rheological properties are most useful for measurements of cooking rate of textile and high water content various foods such as meat and others, and are useful too for designing and controlling [52-54] the various food transforming apparatuses in food industry.

The rate equations for the changes of the various physical properties were postulated as the empirical nth-order rate equation and so on by using the non-linear least square method[55-57] and the electronic computer (FACOM M-200 in the Computation Center of Nagoya University etc.).

DESCRIPTION OF INSTRUMENT

1. Textural instrument

Textural properties[50,58-61] of gel and solid foods have been evaluated, usually by the rheological tests such as the compression, extension, creep and relaxation ones. The rheological properties are very useful tools for the elucidation of the chemical and physical components of foods, moreover they are important in investigation of the mouthfeel[62] of foods. For these purposes, General Foods Texturometer[63], The Instron Universal Testing Machine [64], Rheometer[65], Rheolometer[66], Tensipresser[67] and so on are very useful, because these instruments can supply reliable and broad rheological data.

It is however very expensive to obtain by these instruments the rough parameters which are the operating properties in the transforming process of foods. Therefore, in previous papers[49,50], we studied a simple convenient and cheap textural instrument. But this instrument can be used for measuring the rheological data of gel and soft solid foods only. It has other weak points which are the bend of the sample support lower plate made from a thin copper alloy plate and the temperature sensitiveness of the strain gauge on the support plate. Therefore, we designed an improved instrument which can be used for the harder solid foods.

With the instrument in Fig. 1, we can obtained the compressing properties. But it can be used also to determine the other rheological properties such as the tensile, shear properties and so on, just changing the crosshead and the sample support plates.

The behavior of foods in compression is one of the easiest yet most important mechanical tests for obtaining the textural properties in the various transforming

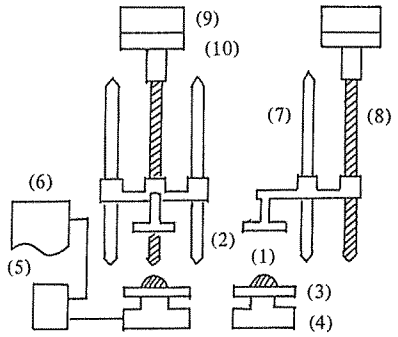

Fig.1 Experimental apparatus
(1) sample, (2) crosshead plate, (3) sample support plate, (4) load cell, (5) strain amplifire, (6) voltage recorder, (7) slide shaft. (8) screw shaft, (9) synchronous motor, (10) gear head.

processes of foods. The test requires only two flat parallel plates, one fixed and the other moving at a preditermined rate to impose strain on the test sample. The sample was placed on the fixed plate.

A 100 kg load cell (Type 9E01-L3, Nippon Denki Sanei Co., Ltd., Japan) was set under the fixed plate. The load cell had a smaller temperature sensitiveness than the strain gauge plate used in the previous instrument. The load cell was connected to a dynamic strain amplifier (Type 6M62, Nippon Denki Sanei Co., Ltd., Japan), and finally to a voltage recorder (Type 3056-22, Yokogawa Hokushin Denki Co., Ltd., Japan). The force-deformation relationship of samples can be obtained on the recorder.

The recorder was used on the range of 10 mV/cm and so on for the ATT=0.01 of strain amplifier. The chart which had a full length of 24 cm was used at a speed of 6 cm/min. The calibration between the force and the recording chart hight was obtained by using a balance weight. The weight was evaluated 17.4 kg for a recording chart hight of 10 cm on the range of 10 mV/cm.

The crosshead plate which could be moved at a constant rate, was connected to the driving system that was made by a slide and a screw shaft (stainless steel, 20 × 1.2ϕ cm, 56 pitch/10 cm) as shown in Fig. 1, and finally, to a cynchronous motor (Type SH10P20, Nippon Servo Co., Ltd., Japan). This motor had rotational frequency of 1800 rpm and an electric power of 20 W. The previous instrument had been made by using a pulley system. It had a lower power motor of 15 W. Therefore, it could not be used for hard solid foods. A gear head system (Type 10H30L, Nippon Servo Co., Ltd., Japan) was connected to the motor, and the rate of the crosshead plate could be changed by changing the gear head system. A crosshead speed of 10.6 cm/min was used by means of a gear head system which could be changed to a rotational frequency of 60 rpm.

2. Textural measurements

Textural descriptions of solid foods which show "how the food behaves on mastication in the mouth" have been evaluated, usually by the tests of the mechanical properties which defined "the behavior of the material under applied forces" and the rheological properties which defined "the relationship between stress and strain"[59].

For the measurements of the textural properties, General Foods Texturometer[63], The Instron Universal Testing Machine[64], Rheometer[65] are very useful, because from

these stress-strain curves we can obtain the various parameters such as hardness, cohesiveness, elasticity, adhesiveness, brittleness, chewiness, and gumminess.

Rheological models[50, 58-61] are useful tools for the evaluation of the mechanical properties of foods. The basic elements of the models are the elastic, plastic and viscous elements which denote by a spring, a friction and a deshpot element symbol. Additional elements are contact, fracture elements[68,69] and so on. The Maxwell, the Kelvin-Voight and the Peleg's general element mechanical models[68,70] which are made by combinating the basic elements have been often used. These models can be obtained from the force-deformation, creep and relaxation data.

The moving system of the crosshead plate in our instrument is rather simple, therefore, the creep and relaxation data could not be obtained accurately. However, the compression, tensile, penetration and shear data which can be used as the operating properties on the food processing can be easily obtained by our instrument. As this instrument is cheap, it can be used in the sensorial parts and so on of the food processing.

The investigations about the rheological properties and the mouthfeel of cooked soybean were reported by Okabe[71]. The measuring method of the hardness and stickieness were optima results but the clearance used in our instrument can not be accurately obtained. Therefore, in this paper the compression testing only was done.

3. Force-deformation data

The force-deformation or the stress-strain data can be obtained from the compression test of foods. Due to the complex relationships of many food materials and so on, the Peleg's general element mechanical model[68,70] and others have been proposed. The Peleg's model is the four element model, based on the Maxwell body in which two restrictions have been incorporated in the form of fracture elements.

Force-deformation curves have been translated into "true" stress-strain curves by taking into account the cross-sectional area expansion and the change in specimen length during compression. The cross-sectional area of the specimen is considerably expanded and therefore can not be approximated by the original area. For an incompressible material and with the assumption that the specimen retains its shape during deformation[72]:

$$P_t = F / A_t \tag{1}$$

$$\text{where,} \quad A_t = A_0 \{ L_0 / (L_0 - \Delta L) \} \tag{2}$$

where, P_t (dyn/cm^2) is the true stress, F(dyn) is the compressing force, A_t and A_0 (cm^2) are the actual and original cross-sectional area, L_0 and ΔL (cm) are the original and deformation length. The true compressive strain under these condition is[72]:

$$\varepsilon_t = \ln \{ L_0 / (L_0 - \Delta L) \} \tag{3}$$

where, ε_t(−) is the true strain.

For a small deformation range the stress and strain can be approximated based on the original cross-sectional area and length as follows[73]:

$$P_0 = F / A_0 \qquad \varepsilon_0 = \Delta L / L_0 \qquad (4), (5)$$

where, P_0 (dyn/cm^2) and ε_0 (—) are the stress and strain based on the original cross-sectional area and length, respectively.

The breaking or flucture energy for the force-deformation data is [73]:

$$E_f = \int_0^{\varepsilon_f} P d\varepsilon \qquad (6)$$

where, E_f (erg/cm^3) and ε_f (—) are the breaking energy and breaking compressive strain.

In previous papers[49,73] we used agar gel samples, it appears that at higher crosshead speed, higher compression force are registered. The experimental results, shown later, were used only at a set speed.

Culioli and Sherman[74] evaluated compression tests using Gouda cheese samples. They showed that the true stress levels can be influenced not only by the sample dimensions, temperature and deformation rate, but also by the shape of the speciments and the friction at the surfaces between the specimen and the support surfaces of the instrument.

The well defined Peleg's model and the above parameters should be avoided in the case of complex force-deformation behaviour. In this paper, the forces at breaking or flucture points and thrusting or bio-yield point[59] were referred to as the experimental results. The samples were compressed till they broke.

The compression testing of solid foods is now a well-established method for evaluating the properties such as strength, rigidity, toughness and so on. The results were given as the relationships between the recording chart length for force and the one for time. The length h (cm) for force was used as a rheological value.

EXPERIMENTAL RESULTS AND DISCUSSION

1. Materials

The soybean used as sample is the so-called "Outanba Shiro Daizu" harvested in 1983 in Japan. It was bought from the market, and stored in a cooling room at 10°C.

The weight of one grain was approximately 0.368 g and the moisture content was about 15.4% (wet basis). The sample had been weighed on a chemical balance. The weight of the bone drying state of the sample was estimated as having the value of 25 houres drying at 125°C in an electric drying oven (Type DZ-33, Yamato Scientific Co., Ltd., Japan; 30 × 30 × 30 cm). The relation between the weight ratio w_d/w_0 and the drying time θ is shown in Fig. 2. The weight ratio of the sample is expressed as the ratio of the weight of dried soybean w_d (g) and that of raw ones w_0 (g). The curve in Fig. 2 gives the calculated results as shown latter.

The density and volume of one grain were approximately 1.202 g/cm^3 and 0.306 cm^3, respectively. The density of the sample was measured by means of a density measuring bottle (6 × 2.5ϕ cm) at 30°C. The volume was estimated by calculating the values of the weight and density.

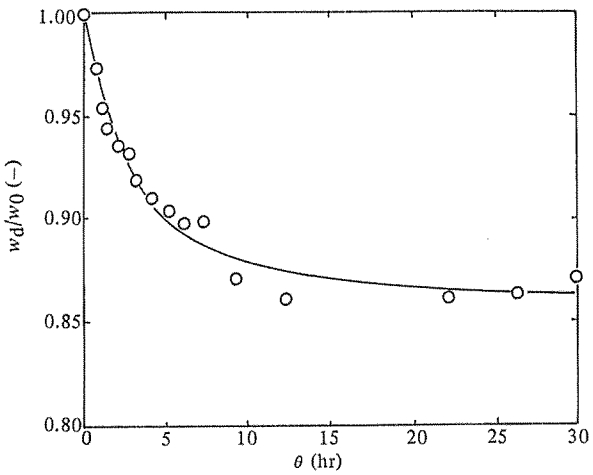

Fig.2 Relation between the weight ratio w_d/w_0 and the drying time θ of raw soybean
Drying condition : 125°C
Observed data : o
Calculated result : ——

2. Soaking procedures

The weighed soybeans (26 grains) were put into a sample basket (stainless steel net, 20 mesh; 6 X 6X 2.5 cm) and entered into the water bath (45 X 30 X 15 cm) which temperature was controlled by thermo unit, and kept at 30°C (Type Minder-Junior, Taiyo Scientific Co., Ltd., Japan) for a fixed time. The water used in the water bath plain was tap water. The soaked soybean was poured out, and the surface water was wiped away. Then the sample was weighed on a chemical balance.

One part the of soaked soybean was used to botain the density, and the other part to obtain the weight of the bone drying state.

The relations between the weight ratios w/w_o and w_d/w_o, density ρ_s and the soaking time θ are shown in Fig. 3. w_0, w and w_d (g) are the weight of raw, soaked and bone drying state soybean. The solid curves in Fig. 3 are the calculated results as shown latter.

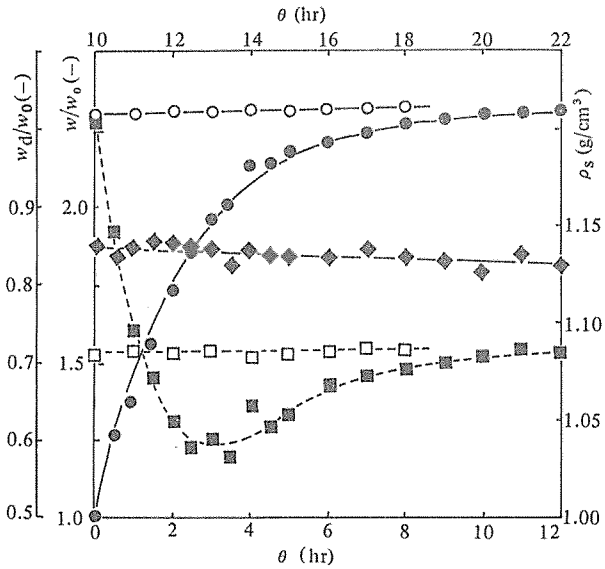

Fig. 3
Relations between the weight ratio w/w_0, w_d/w_0, density ρ_s and the soaking time θ of raw soybean
Soaking temperature : 30°C
Observed data : w/w_o w_d/w_0 ρ_s vs. θ
for low line ● ◆ ■
for upper line ○ □
Calculated results : ———

The curve of the density is not monotonous and has a minimum state. The reason may be perhaps that the production of the respiratory gases occured in the space between the coat film tissue and the inner components of the soybean. These results are nearly the same as the previous ones[7].

3. Cooking procedures

The raw and soaked (30°C, 10 hours) soybeans (26 grains) were put into a sample basket and entered into the cooking pot (20ϕ × 30 cm) which was filled up with boiling tap water at 100°C for a fixed time.

The cooked soybean was poured out quickly, and put into the water of 30°C for 2.5 minutes in order to stop the cooking of the sample. After the surface water was wiped away, the weight of the sample was weighed on a chemical balance. One part of cooked soybean was used to obtain the density, and finally to obtain the rheological value, and the other part was used to obtain the weight of the bone drying state. The rheological value of the sample measured by the method as shown latter.

The relations between the weight ratios, rheological values, density and the soaking time are shown in Figs. 4 and 5. The solid curves in Figs. 4 and 5 are the calculated results as shown latter.

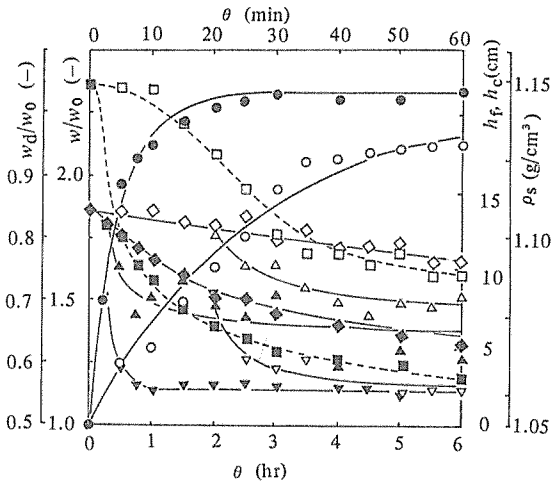

Fig. 4 Relations between the weight ratio w/w_0, w_d/w_0, rheological value h_f, h_c, density ρ_s and the boiling water cooking time θ of raw soybean
Cooking temperature : 100°C
Observed data : w/w_0 w_d/w_0 ρ_s h_f h_c vs. θ
for low line ● ◆ ■ ▼
for upper line ○ ◇ □ ▽
Calculated results: ———

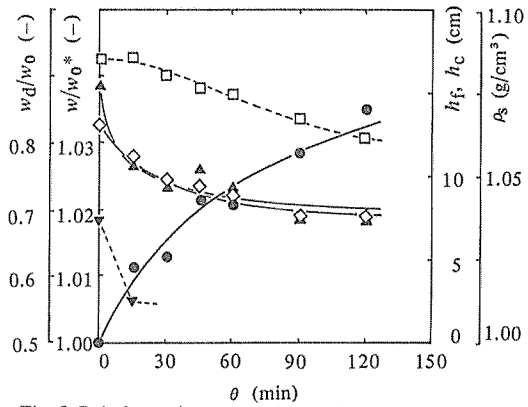

Fig. 5 Relations between the weight ratio w/w_0, w_d/w_0*, rheological value h_f, h_c, density ρ_s and the boiling water cooking time θ of soaked soybean
Soaking conditions : 30°C, 10 hr.
$w_0*/w_0 = 2.288$
Cooking temperature : 100°C
Observed data : w/w_0 w_d/w_0 ρ_s h_f h_c vs. θ
for low line ● ◇ □ ▲ ▼
Calculated results : ———

4. Microwave treatments

The soaked (30°C, 10 hours) soybean (26 grains) were bundled loosely in a chloride polyvinylidene sheet (Trade-mark Kure-wrap, Kureha Kagaku Co., Ltd., Japan) and entered in an electronic range (Type NE-6330, National Denki Co., Ltd., Japan; 2450 MHz, Input 1.15kW, Output 600, 240, 180W, 34 × 34 × 18 cm) using an output power of 180 or 240 W for a fixed time.

The bundled sample was set on the insulator of a foam polystyrol disk (1.5 X 14ϕ cm) which was put inside together with sample. This insulator was used to avoid the conduction of heat to the large glass dish set in the range. This range has a stirring fan which can be stired the generated microwave from a magnetron. The range has a large glass dish too (31ϕ cm) which can be turned.

The cooked soybean was quickly removed from the bundled sheet and was put into water of 30°C for 2.5 minutes, in order to stop further cooking. After that the surface water was wiped away, the rheological value was measured by the method as shown latter.

The relations between the rheological values and the cooking time are shown in Fig. 6. The relationships between the rheological value and the microwave energy cooking time however could not be obtained. When the water content of the sample decreased through evaporation, the decreased rheological value increased again. The reason for this may be perhaps the vapor produced in the space between the bundled sheet and the inner samples of the soybean. The bundled sheet puffed out due to the produced vapor, the times were 70–75 and 50 seconds for the output poweres of 180 and 240 W, respectively. The temperature of the sample could not be measured, because the thermocouple could not be treated in the microwave range.

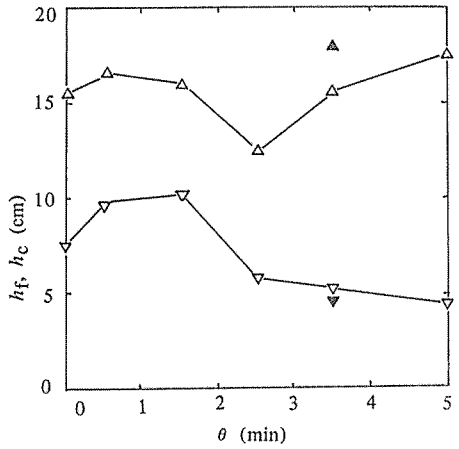

Fig. 6 Relations between the rheological value h_f, h_c and the microwave energy cooking time θ of soaked soybean bundled loosely by chloride polyvinyidene sheet
Soaking conditions : 30°C, 10hr, w_0^*/w_0=2.288
Microwave conditions : 2450 MHz, w_0^*=21.69 g
Observed data : h_f h_c vs. θ
180 W △ ▽
240 W ▲ ▼
Calculated results : ———

5. Texture measurements

The characteristics of the force-deformation curves were observed for the cooking of the raw and soaked soybeans with boiling water and microwave energy. Samples of the results are shown in Figs. 7 and 8. The points in Figs. 4–6 represent the mean values of four to six readings. For the raw soybean, the curve was not obtained, because the hardness was perhaps too high for our instrument.

The curves of the whole soybean showned a complex behaviour, because the rupture to the two cotyledons occured occasionally. Therefore, we used the half portion separated from the two cotyledons as the sample for the texture measurements as shown Fig. 1.

In most of the specimens, the curves tended to be of no smooth increase and a thrusting or bio-yield point was observed after contact with the crosshead plate. That is, it

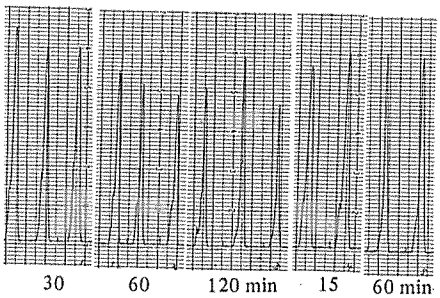

Fig. 7 Force-time relationships for the boiling water cooking (100°C) of soybean (left figure)

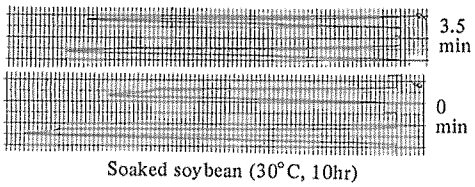

Fig. 8 Force-time relationships for the microwave energy cooking (180°C) of soybean (upper figure)

seemed that minor destruction was produced as the specimens were compressed. The thrusting or bio-yield point and breaking or fluctuate point were measured too for the experimental results. These results indicated that the rheological values of these points were h_c and h_f, respectively. From these curves, the true stress nor the strain to rupture and the rupture energy were not determined, because the data were very scatterd and the curves obtained had a complex behaviour.

RATE EQUATIONS AND DISCUSSION

1. Rate equations

The changes of the physical values on the soaking and cooking of soybean can be expressed in the following rate equations.

nth-order rate equation:

$$dx / d\theta = k_n (1-x)^n \tag{7}$$

S-shape rate equation:

$$dx/d\theta = k_{n\alpha} (1-x)^n (x+\alpha) \tag{8}$$

where, $$x = |y-y_0| / |y_e-y_0| \tag{9}$$

where, y (example unit: g), x (−) and θ (min) are the physical values, the transforming ratio and the time, respectively. Subscripts 0 and e show the initial and equilibrium states. k, n and α are the rate parameters which can be obtained from the experimental data of y or x vs. θ.

The values of n and α are interesting, because these values indicate the form of the curves. In the previous paper[17], we studied the relationships between the rate parameters n and α and obtained the results as follows: nth-order rate equation can be used for $\alpha \geqq 0.75n$, but S-shape rate equation have to be used for $\alpha \geqq 0.75n$.

The values of k can be indicated by using the following Arrhenius equation for the chemical reaction, cooking and so on, but for the physical properties the values can not be used this equation.

$$k = k_0 \exp(-E / R_g T) \tag{10}$$

where, T (°K) is the temperature and R_g=1.987 cal/g-mol·°K is the gas constant. k_0 and E are the parameters which can be obtained from the data of different temperatures. k_0 and E stand for the frequency factor and the activation energy, respectively.

2. Calculation method of rate parameters

The experimental data are generally obtained as integral data of y or x vs. θ. However the derivative values of $dx/d\theta$ in the rate equations can not be obtained reliably from the data x vs. θ. Therefore, the differential method is not better than the following integral method. The analytical integral method can be used for the simple rate equations such as Eq. (7), but not for the complex rate equations such as Eqs. (8) and so on.

The numerical integral method is most successful when using a digital electronic computer. Thus, the rate equations were integrated numerically using the Runge-Kutta-Gill method, and the rate parameters were calculated by a non-linear least square method[55-57]. The values of the following standard deviation σ (–) for the variable x were minimized.

$$\sigma = \left(\sum_{i=1}^{N} (x_{obs} - x_{cal})_i^2 / N \right)^{0.5} \tag{11}$$

where, x_{obs} and x_{cal} are the observed and calculated values of x, and N is the total number of data.

We used the digital electronic computer FACOM M-200 in the Computation Center of Nagoya University.

3. Calculated results

The initial and calculated values of the rate parameters in Eq. (7) are listed in Tables 1–4. The calculated results obtained by using the parameters are shown in Figs. 2–5. w_o* (g) in Table 4 represents the weight of the soaked soybean. The calculated results are satisfactory enough. However, the results for the rheological values on the boiling-water-cooking of raw soybean were set so that the initial time of rate equation was 20 minutes, because these values could not be obtained from raw soybean.

The rate parameters for the density were not calculate, because these results are too complex. The S-shape relations of the density to the cooking time can be expressed by

Table 1. Calculated results on the drying of raw soybean

Drying temperature: 125°C

	Initial values			Calculated values		
	k_n (min^{-1})	n(–)	σ (–)	k_n (min^{-1})	n (–)	σ(–)
A	4.46×10^{-3}	1.00	0.0575	5.55×10^{-3}	1.46	0.0451
A	7.15×10^{-3}	1.5*	0.0667	5.72×10^{-3}	1.5*	0.0452

where, A: $y=w_d/w_0$, *: fixed values w_0=0.368g/l grain, w_{de}/w_0=0.858, R_0=0.418cm, ρ_0=1.202g/cm^3

Table 2. Calculated results on the soaking of raw soybean

Soaking temperature: 30°C

	Initial values			Calculated values		
	k_n (min^{-1})	n (–)	σ (–)	k_n (min^{-1})	n (–)	σ (–)
A	6.85×10^{-3}	1.00	0.0190	6.36×10^{-3}	0.87	0.0159
A	6.85×10^{-3}	1.0*	0.0190	6.92×10^{-3}	1.0*	0.0189
B	3.79×10^{-3}	1.00	0.304	1.70×10^{-3}	0.38	0.246
B	2.99×10^{-3}	0.5*	0.312	1.78×10^{-3}	0.5*	0.246

where, A: $y=w/w_0$, B: $y=w_d/w_0$, w_0=0.368g/1 grain, w_e/w_0=2.310, R_0=0.418cm, R_e=0.572cm, ρ_0=1.202g/cm^3, ρ_e=1.084g/cm^3

Table 3 Calculated results on the boiling water cooking of raw soybean

Cooking temperature: 100°C

	Initial values			Calculated values		
	k_n (min^{-1})	n (–)	σ (–)	k_n(min^{-1})	n(–)	σ(–)
A	3.00×10^{-2}	1.00	0.0598	3.61×10^{-2}	1.05	0.0439
A	3.00×10^{-2}	1.0*	0.0598	3.52×10^{-2}	1.0*	0.0441
B	6.86×10^{-3}	1.00	0.0556	6.90×10^{-3}	0.74	0.0423
B	6.86×10^{-3}	1.0*	0.0556	7.71×10^{-3}	1.0*	0.0471
C	2.35×10^{-2}	1.00	0.244	1.09×10^{-1}	4.63	0.137
D	7.98×10^{-2}	1.00	0.130	4.80×10^{-1}	2.59	0.0802

where, A: $y=w/w_0$, B: $y=w_d/w_0$, C: $y=h_f$, D: $y=h_c$ w_0=0.368g/1 grain, w_e/w_0=2.332, R_0=0.418cm, R_e=0.580cm, ρ_0=1.202g/cm^3, ρ_e=1.054g/cm^3, h_{f0}=12.4cm, h_{c0}=8.4cm, h_{fe}=3.8cm, h_{ce}=1.9cm (Subscript 0 of h : θ=20 minutes)

Table 4 Calculated results on the boiling water cooking of soaked soybean

Soaking conditions: 30°C, 10 hours
Cooking temperature: 100°C

	Initial values			Calculated values		
	k_n(min^{-1})	n(–)	σ (–)	k_n (min^{-1})	n(–)	σ(–)
A	1.92×10^{-2}	1.00	0.0608	2.14×10^{-2}	1.33	0.0553
A	1.92×10^{-2}	1.0*	0.0608	1.82×10^{-2}	1.33	0.0553
B	3.30×10^{-2}	1.00	0.0721	2.72×10^{-2}	0.99	0.0561
B	3.30×10^{-2}	1.0*	0.0721	2.84×10^{-2}	1.0*	0.0561
C	1.96×10^{-2}	1.00	0.144	1.16×10^{-1}	5.14	0.0570

where, A: $y=w/w_0$*, B: $y=w_d/w_0$, C: $y=h_f$, w_0=0.368g/1 grain, w_0*/w_0=2.288, w_e/w_0*=1.035, R_0=0.418cm, R_0*=0.570cm, R_e=0.581cm, ρ_0=1.202g/cm^3, ρ_0*=1.084g/cm^3, ρ_e=1.061g/cm^3, h_{f0}=15.5cm, h_{fe}=3.8cm

using Eq.(8), but to the soaking one at 30°C can not be formulated.

The rate parameters for the microwave energy cooking was not calculate, because their results were very complex too.

The values of n on the soaking and cooking of raw and soaked soybean by the weighing method are nearly one, but by the rheological method are nearly five. From this result, we can induce that the soaking phenomena are very complex.

The Arrhenius equation on the soaking and cooking of raw soybean with tap and boiling water are shown as follow:

$$k_{n=1} = 40.17 \exp(-5.221 \times 10^3 / R_g T) \qquad (12)$$

The values of the apparent activation energy for the soaking and cooking of soybean is less than the value of 7.31×10^3 cal/g-mol reported in a previous paper[7]. This perhaps is a results of the temperature of 100°C used which is slightly lower[7] than each other temperatures.

The values of $k_{n=1}$ in this paper are less than in the previous one[7]. This is due to the different kind, preservation and producing district of the soybeans used.

The textural investigations on the soaking and/or cooking of beans have been reported by many researchers[71,75-88]. The studies of the activation energy on the soaking and/or cooking of beans however are few [7,8,82,85,85-91]. The values of the apparent activation energy have been reported as being $35.5-43.5 \times 10^3$ cal/g-mol for black bean, soybean and so on at 98–127°C[82]; 9.4×10^3 for soybean at 5–70°C[89]; 7×10^3 for soybean at 20–40°C[90]; $19.1-38.9 \times 10^3$ for black bean at 90–135°C[85], and $9-13 \times 10^3$ for soybean at 20–50°C[91].

The values by the weighing method are generally neary 10×10^3 cal/g-mol, but those obtained by the textural method are from 20 to 40×10^3 cal/g-mol. From these results, we can presume that the soaking and/or cooking at less than 100°C are mainly physical hydrating phenomena, while the cooking at near 100°C or higher temperature are perhaps mainly chemical reactions.

The studies for the soaking and/or cooking of beans by microwave energy are scarce[75,92] too.

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SUMMARY

The texture of foods is an important physical property in the designing equipment for

controlling various food processes and for product quality control.

In previous papers[49,50], we studied the simple convenient and cheap textural instrument. This instrument however can not be used for measuring the rheological data of hard materials. Therefore, in the present study we made an improved instrument which can be used for the hard solid foodstuffs.

The changes of various physical properties including the rheological value on the soaking and cooking of soybean were investigated. The results by the weighing method which we used in previous paper[7] and by the rheological method using improved instrument were obtained in due manner, and the rate equations were postulated by using a nth-order rate equation.

NOTATIONS

A : cross-sectional area (cm^2)
E : activation energy (cal/g-mol)
E_f : breaking energy (erg/cm^3)
F : froce (dyn)
h : length for force indicated rheological values (cm)
k : parameter (min^{-1})
k_o : frequency factor (min^{-1})
L : length (cm)
ΔL : deformation length (cm)
N : number of data (—)
n : parameter (—)
P : stress (dyn/cm^2)
R_g : gas constant (cal/g-mol·°K)
T : temperature (°K)
w : weight (g)
w_0* : initial soaked weight (g)
x : transforming ratio (—)
y : changing physical value (example: g)
α : parameter (—)
ε : strain (—)
θ : time (min) or (hr)
ρ_s : density (g/cm^3)
σ : standard deviation (—)

Subscripts

0 and t : original based and true values
c and f : thrusting or bio-yield and breaking or fluctuate points
0, e and d : initial, equilibrium and bone states
obs and cal : observed and calculated values

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簡便なテクスチャー測定用装置の製作と大豆のクッキングにおける各種物性値測定に関する研究

久保田清・江坂宗春・鈴木寛一

食品のテクスチャーは，食品製造工程の制御操作などを進める場合に重要となるパラメーターの一つである。前報[49]において，軟固体状食品のレオロジー的特性が測定できる装置の試作と，寒天ゲルのレオロジー的特性の測定に関する研究を行ってきた。

本研究では，固体状食品の特性が，前報のものよりもより広い範囲により精度よく測定できる装置の製作と，それの大豆のクッキング操作に対する利用に関する研究を行った。

本装置は，市販のものと比較すると，複雑な構造解析などを進めることができるレベルの特性の測定が困難であるという欠点があるが，簡便で安価であるという特徴があるため，操作物性の変化を測定するセンサーなどとして工程に組み込んで利用していけるものであると考えられる。