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Measurement of Elastic Properties of Kamaboko and Other Food Gels by a New Simplified Rheometer

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Abstract

A simplified rheometer was manufactured to measure the elastic properties of kamaboko and other food gels. Mechanical force applied to the gel through the penetration of a plunger was recorded using a potentiometric recorder. The gel quality of laboratory made surimi products and that of kamaboko and meat products in the market was also measured using this rheometer. The data obtained maintained a strong correlation with those from corresponding folding and sensory tests. A high correlation ($p < 0.001$) was observed between the textural parameters obtained using the simplified rheometer and a standard rheometer generally used in Japanese laboratories.

Introduction

The texture of kamaboko type fish gel has long been tested instrumentally for the quality control of products (Okada and Yamazaki 1957; Shimizu and Shimidu 1960). Various instrumental devices depending on the mastication force on foods like punching, shear, tensile or compression forces have been used. Puncture test is one of such empirical gel quality testing methods. This test is conducted using a rheometer by penetrating a plunger into the gel at a constant speed. The depth of penetration is usually predetermined and held constant (Halmos 1995). In this test, the maximum force needed for a plunger to penetrate the gel is measured. Rheometers available in the market are highly sophisticated and can produce authenticated data. However, these instruments are so expensive that the cost is beyond the means of many researchers, especially in developing countries. On the other hand, the principle behind the function of a rheometer can be imitated to a simplified version thereby reducing a greater portion of its cost. This can help researchers to adapt said measurement technique especially in developing countries at the least cost. A number of hand-made rheometers were manufactured to cover the cost of the instrument (Okada 1963; Niwa et al. 1972). However, they were too complicated both in structure and in function. In this study a simplified rheometer was manufactured to conduct the puncture test and the textural properties of kamaboko and other food gels were measured with greater accuracy compared to other hand-made rheometers.

Materials and Methods

Manufacture of simplified rheometer and its function

Induction motor (1H7PF10N) and gear head (7H18FN, gear ratio 1:18) were obtained from Japan Servo Co. Ltd., Tokyo. The specifications of the induction motor were as follows: power source voltage AC 100V (single phase), rated output 10 W, revolution per min. 1200 rpm in 50Hz and 1500 rpm in 60Hz. A linear variable DC differential transformer (Shinko Denshi Co. Ltd., Tokyo) used to measure force had the following characteristics: applied voltage DC 4 - 10V, output voltage DC 0.6V.mm^{-1} at an applied voltage of 5.72V. All other electrical parts were purchased from a retail electric store in Tsu City. The mechanical structure of the rheometer was made of steel and stainless steel (Fig. 2). In this rheometer, AC100V was chosen as the power source voltage. If other voltage is chosen the rheometer should be connected to the power supply through a power transformer of a secondary voltage of 100V or the rated voltage of the electrical parts like pilot lamp, relay, induction motor and the transformer must be adapted to the applied voltage. These electrical parts of various rated voltages (110~~115V and 200~~220V) can be obtained from every Japanese maker.

The rheometer is composed of two main units, a sample stage driving unit illustrated at the top of Figure 1 and in Figure 2 (left) and a force measuring unit illustrated at the bottom of Figure 1 and at the left of Figure 2. The electronic portions of the stage driving and force measuring units were installed as per the electronic circuits shown in Figure 1 (top and bottom, respectively). In the stage driving unit, an induction motor (IM) controls the “UP” and “DOWN” movement of the stage through an up & down switch (S2), a relay (R) and various other switches (lower limit switch, LS-l; upper limit switch, US-u; emergency switch, EMS). The key element in the force measuring unit is a differential transformer, DT (Fig. 1, bottom; Fig. 2, left), to which a plunger is connected. During the penetration of the plunger into the gel, the core (C) of DT moves upward and the applied force of the plunger is recorded by a potentiometric recorder. The DT is fed from a DC transformer (12V, 30 mA). The

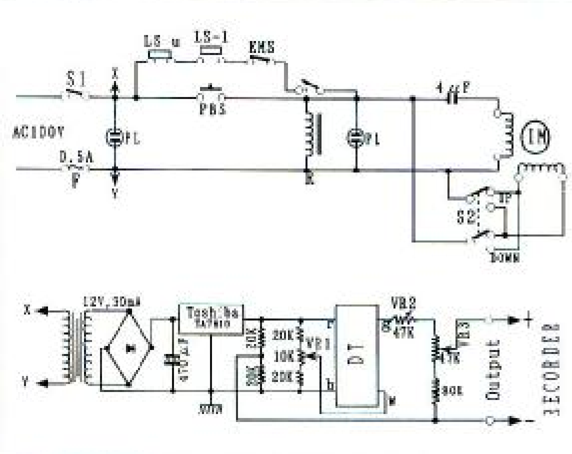

Fig. 1. Circuits for sample stage driving unit (top) and force measuring unit (bottom). S1: power switch; LS-u & LS-l: upper limit & lower limit switches; S2: up & down switch; PBS: starter; EMS: emergency switch; F: fuse; PL: pilot lamp; R: relay; IM: induction motor; DT: differential transformer; VR1: zero balance; VR2: sensitivity adjustment 1; VR3: sensitivity adjustment 2; X & Y: connection between top and bottom circuits; four wires of DT - r: red, g: green, b: black and w: white.

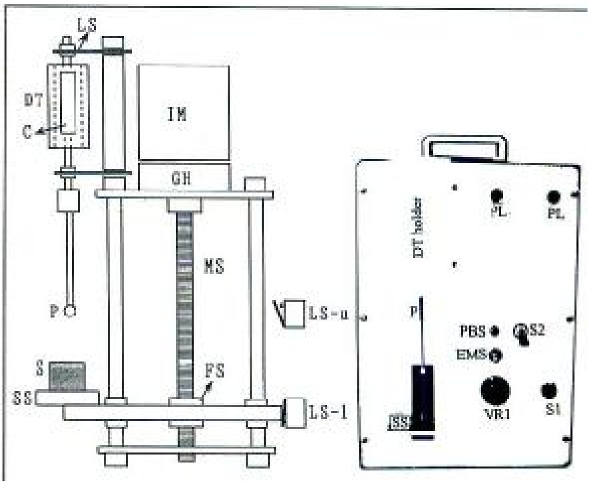

Fig. 2. Schematic diagram of sample stage driving unit (left) and outer features of simplified rheometer (right). DT: differential transformer; C: core; P: plunger; SS: sample stage; GH: gear head; MS: male screw; FS: female screw; S: sample; LS: leaf spring.

"red" and "black" ends (wire) of the DT are connected to the DC transformer through condensers and transistors as shown in the circuit. The "green" and "white" ends of the DT are connected to the recorder through variable resistance (VR1, VR2, VR3) for zero balance and the sensitivity adjustment of the recorder. A photograph at the right of Figure 2 shows the outer feature of the rheometer. The weight of the rheometer is 6.5 kg and the size including projections is 35 cm (height) x 23 cm (width) x 21 cm (depth). All electronic parts are readily available in electrical shops. The outer case including the inner mechanical structures were constructed in the laboratory. The total amount of money spent to construct this instrument is approximately US $1,000, whereas, a Fudoh Rheometer (Fudoh Kogyo Co. Ltd., Japan, NRM 2010J-CW) costs about US $8,000 in the international market.

After turning the power switch (S1) "on", the rheometer is warmed up for about 10 min. to stabilize. An "up & down" switch (S2) is set to "UP" (Fig.1) and the sample gel is placed at the center of the sample stage (SS). The recorder baseline is adjusted to 0 mV with a zero balance (VR1). The relay (R) is turned 'on' by pressing the starter (PBS). A male screw (MS, 6 mm diameter) mechanically connected to the induction motor (IM) through a gear head (GH) starts to revolve (Fig. 2). A horizontal bar, into which a female screw (FS) is buried, ascends together with the sample stage (SS) at a speed of 10 cm.min^{-1}. The gel is gradually compressed between the sample stage (a horizontal plate) and the tip of plunger (P) and is finally broken. The upward movement of the sample stage automatically stops at a constant height upon the contact of the horizontal bar to a lever of upper limit switch (LS-u). The micro-switches of leaf spring type are substituted for this upper limit switch and the lower limit switch mentioned later.

If an ongoing test needs to be stopped at the middle, the upward movement of the sample stage could be stopped by turning the emergency switch (EMS) ‘off’. After the test, the up and down switch is turned to “DOWN”. Once the starter is pressed, the male screw revolves reversely. The sample stage descends and stops at its original height upon the contact of the horizontal bar to the lever of lower limit switch (LS-l).

During the compression of the gel, a core (C) of the differential transformer, to which the plunger is connected, is pushed up. Since the output voltage of the rheometer is proportional to the upward motion of the core sustained between two leaf springs, change in the force applied to the tip of the plunger could be recorded using a DC potentiometric strip chart recorder (Yokogawa Electric Co. Ltd., Tokyo, Technicorder 3046, 7 sensitivity ranges and 8 chart speed ranges) at a full-scale sensitivity of 100 mV. If an exclusive recorder is used for this rheometer, the full-scale sensitivity of 50-100 mV and the chart speed of 5-10 cm.min^{-1} are needed. The relationship between the force and the output voltage is calibrated by pushing the plunger up using a laboratory scale. The force required to push the plunger up is recorded from the laboratory scale and simultaneously, the output voltage due to the movement of the pen is recorded in the recorder’s chart. The full-scale of the recorder is adjusted through sensitivity adjustments 1 and 2 (VR2, VR3, trimming resistors) under the condition that the force is applied to the plunger.

Kamaboko and other food gels

Kamabokos and other food gels were supplied by a department store in Tsu City. Some of the suwari (set gel), modori (returned gel) and kamaboko gels were prepared in our laboratory from Alaska pollack *Theragra chalcogramma* frozen surimi (Ocean Trawl Inc., Alaska, SA grade). After being thawed overnight at 4 °C, the surimi was minced and ground with 3% NaCl and 30% water in a mechanical mixer (Taisho Denki Co. Ltd., Tokyo, Ladies Mixer, KN 100) for 20 min. in a cold room. Salt-ground paste was stuffed into polyvinyledene chloride tube (2.8 cm diameter) and incubated in water baths at 30 ° or 60 °C to make set gel and returned gel, respectively. A portion of such incubated gel was further cooked at 85 °C for 30 min. to produce kamaboko. The resulting gels and kamabokos in the tube were cooled in iced water for 30 min. and kept at room temperature for 1 hour before making any measurement.

Texture measurements

Puncture test: After unwrapping, the gels were cut into test pieces of 2.5 cm height. Puncture test was carried out at a stage speed of 10 cm.

min^{-1}. and a chart speed of 6 cm.min^{-1}. using the simplified rheometer equipped with a spherical plunger (5 mm diameter, Fudoh Kogyo Co. Ltd., Tokyo). Breaking force in g and breaking deformation in cm were read from the recording chart.

Folding test: Folding test was carried out by folding the sample disc of 1 mm thickness into halves and quarters. The grades were: a - no crack when folded into quarters; b - no crack when folded into halves but one or more cracks when folded into quarters; c - one or more cracks when folded into halves; d - broke but did not split into halves; e - split into halves when folded into halves.

Sensory tests: A nine-person panel composed of students and staff personnel as described by Poon et al. (1981) provided the sensory assessments. Prior to sample testing, panelists were familiarized with the attribute descriptions, anchor points and instructions relating to completion of descriptive score cards. Pretests were also undertaken with selected samples to familiarize the panelists with the test samples as well as the measurement procedure. Spherical discs of 1 mm thick gels were supplied to each panelist for them to recognize the quality.

Softness/firmness was defined as the amount of force required to bite through the sample using incisors while the gel strength was evaluated based on the numerical scores up to 10. A panel score of ≤ 5 was taken for frail or poor quality gel. Overall scale was 1 = very soft; 10 = extremely firm. Chewiness/rubberiness was defined as the amount of effort the panelist had to exert in chewing to prepare the sample for swallowing. These definitions are adaptations of Szczesniak's textural definitions developed to be used in sensory analysis (Szczesniak et al. 1963). The scale for chewiness/ rubberines was 1 = not chewy/rubbery; 10 = extremely chewy/rubbery.

Statistical analysis

Statistical analyses of the data were done using regression analysis, t-test, goodness-of-fit and ANOVA (STATGRAPHICS, 1992). Least significant difference at $p < 0.05$ was used to determine the significant differences between mean values.

Results and Discussion

As shown in Figure 3, the output voltage of the rheometer linearly increased with the increment of force applied to the tip of the plunger. A high correlation was recognized between the voltage and the force ($\chi = 0.999$, $p < 0.001$). If the leaf spring (LS) that sustains the core (C) of the differential transformer is made of a blade of metal saw (thickness: 1 mm; width: 10 mm; length: 35 mm), the force of 2 kg could be measured to its maximum. As the usual kamaboko was compressed, its surface gruadually became dented and finally the gel was broken by the penetration of the plunger. At this time, the force gradually increased with the progress of deformation of

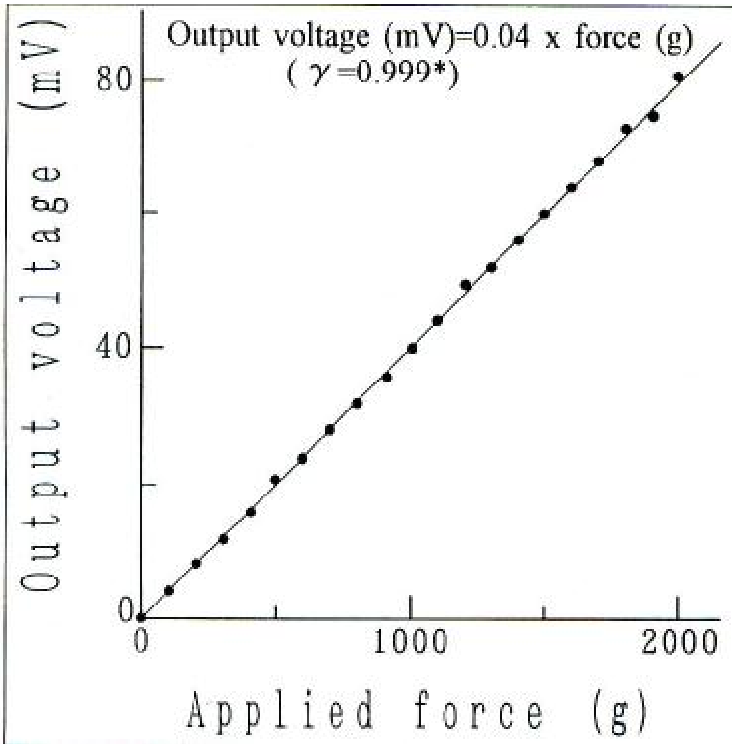

Fig. 3. Calibration curve for the output voltage and applied force. Asterisk shows $p < 0.001$.

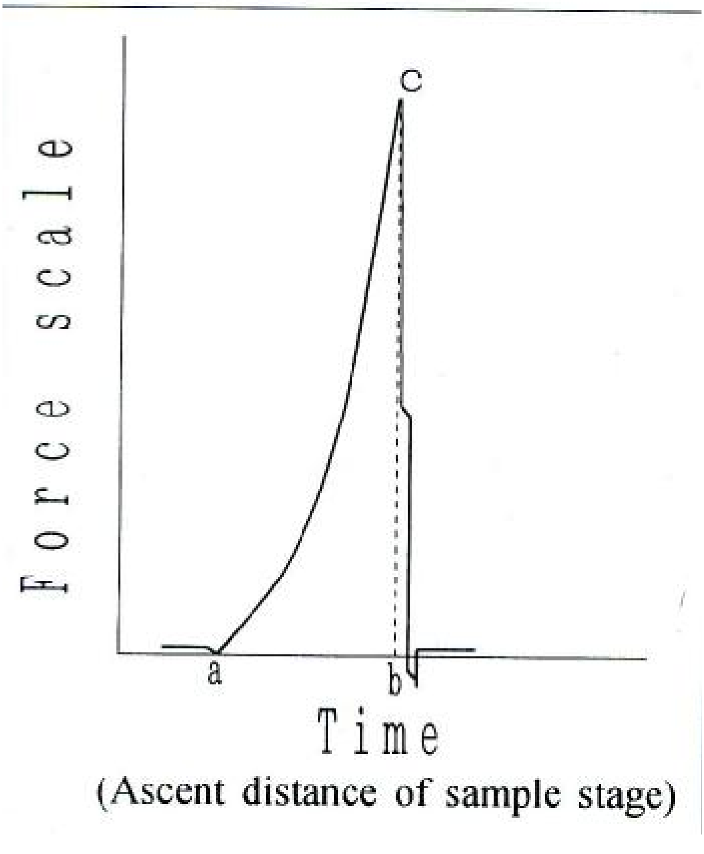

Fig. 4. Typical force-deformation curve for kamaboko recorded by simplified rheometer. a: time plunger gets in contact with sample; b: time of the breaking of sample; c: maximum force at the time of breaking. The breaking force is expressed by **bc** and the breaking deformation, the ascent distance of sample stage until breaking can be calculated from **ab** and the speed of the sample stage.

the gel but suddenly dropped at its breaking as understood from a force-deformation curve illustrated in Figure 4. Based on typical textural parameters, breaking force (BF) is read from a maximum force at the breaking of the gel (**bc**) and the breaking deformation (BD) from a distance of the ascent of the sample stage which could be calculated from **bc** and the speed of the sample. The former is thought to show the hardness of the gel at its biting and the latter to show its stickiness or cohesiveness. Both of these two parameters are equally important in expressing the characteristics of fish gel and the product of these two (BF x BD) are generally used as “gel strength” to quantify kamaboko texture (Shimizu and Shimidu, 1960), half of which is equal to the value of kinetic energy to break the gel (Niwa, 1995). In order to examine the accuracy of this rheometer, the puncture test was also carried out on the same sample analyzed in this study using a standard rheometer with the same type of plunger (Fudoh Kogyo Co. Ltd., Tokyo, Japan, NRM 2010J-CW). Regression of the results of puncture test using simplified versus standard rheometers demonstrated that the two instruments correlated very well for BF, BD and BF x BD, which could be predicted using the regression equations as for BF: SiR = - 5.96 + 1.02 StR (cc= 0.999, $p < 0.001$); for BD: SiR = 0.008 + 0.99 StR (cc = 0.998, $p < 0.001$) and for BF x BD: SiR = - 0.69 + 1.01 StR (cc = 0.997, $p < 0.001$), where SiR is for simplified rheometer and StR is for standard rheometer. The correlation coefficients (cc) were very high in all cases.

Figure 5 shows the force-deformation curves for five food gels made in Japan. “A” is for a very hard and very sticky kamaboko made in Odawara district. Such strong texture is endowed by the exhaustive washing of fish mince, inevitably reducing the amount of water soluble proteins which inhibit the strengthening of the gels. “B” is for a considerably hard and considerably sticky fish sausage, prepared from Alaska pollack frozen surimi, the same starting material as that of a usual kamoboko. “C” is for a moderately hard but less sticky chicken sausage which is not so crisp. “D” shows the curve for a considerably soft and brittle pork sausage which is considerably fatty and “E” is for a very soft and mellow hampen as if it is molten in the tongue like a marshmallow. The hampen is prepared by adding grated yam to shark mince and its peculiar texture is endowed by the numerous fine bubbles it contained. The textural features of the above mentioned gels can be well understood from each curve at a glance.

As well known, the condition of preincubating surimi paste remarkably influences the quality of kamaboko prepared by further cooking at higher temperature. For example, an elastic gel is obtained by incubating the paste at 30 °C (setting), and a kamaboko of good quality is obtainable by cooking the gel further. Incubation of paste at 60 °C, however, gives a brittle gel (returning), and a kamaboko of poor quality is only obtainable by cooking such brittle gel further. In Table 1, the textural parameters of thus prepared gels and kamabokos are compared with the results of folding and organoleptic tests in order to examine the ability of the new rheometer. With increased incubation time at 30 °C, the values of both BF and BD of the gels significantly increased with the increasing scores of organoleptic tests

Table 1. Physical and organoleptic properties of the gels and kamabokos prepared from Alaska pollack surimi.

Gel and Kamaboko		BF (g)	BD (cm)	FT	S/F[2]	C/R[3]
Gel incubated at 30 °C						
for	1 h	280 ± 34^{s}	7.4 ± 0.2^{s}	a	7.0^{t}	6.5^{s}
	2 h	360 ± 42^{t}	8.0 ± 0.4^{t}	a	7.2^{t}	7.5^{t}
	4 h	480 ± 60^{u}	8.5 ± 0.3^{u}	a	7.5^{u}	7.8^{tu}
Kamaboko[1] preincubated						
at 30 °C for	1 h	570 ± 54^{v}	9.4 ± 0.4^{v}	a	8.0^{v}	8.0^{u}
	2 h	630 ± 48^{w}	10.5 ± 0.5^{w}	a	9.0^{w}	8.5^{v}
	4 h	790 ± 65^{x}	11.0 ± 0.4^{wx}	a	9.1^{w}	9.2^{w}
Gel incubated at 60 °C						
for	2 h	120 ± 18^{r}	4.6 ± 0.2^{r}	c	3.3^{s}	2.5^{r}
	4 h	89 ± 11^{qr}	4.0 ± 0.2^{q}	d	2.5^{r}	2.2^{qr}
Kamaboko[1] preincubated at 60 °C						
for	2 h	72 ± 12^{q}	3.7 ± 0.1^{q}	d	2.0^{q}	2.0^{q}
	4 h	60 ± 10^{q}	3.6 ± 0.2^{q}	d	2.0^{q}	2.1^{q}

[1]Gels incubated at 30 ° or 60 °C were made into kamaboko by further cooking at 85 °C for 30 min.
[2]Softness/firmness: scale 1 = very very soft; 10 = extremely firm.
[3]Chewiness/rubberiness: scale 1 = not chewy/rubbery at all; 10 = extremely chewy/rubbery.
Within a parameter, means with different superscripts are significantly different ($p < 0.05$).

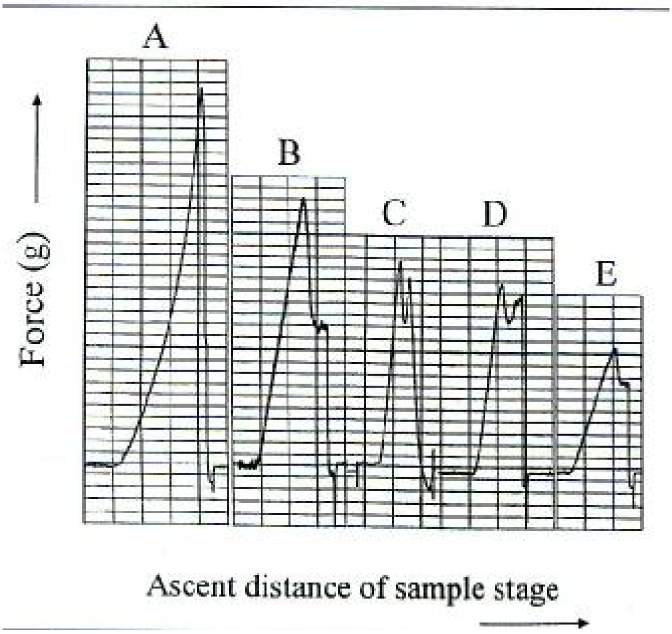

Fig. 5. Force-deformation curve for various food gels recorded by simplified rheometer. A. kamaboko; B. fish sausage; C. chicken sausage; D. pork sausage; E. hanpen.

($p < 0.05$). Such increments in BF and BD values and organoleptic scores were more remarkable in the kamaboko prepared by cooking these gels further at 85 °C. Longer incubation at 60 °C however, decreased both the values and scores of the gel, and further cooking of such gel at 85 °C decreased the values further. Instrumental results strongly correlated (p <

0.001) with the folding and sensory scores in all cases. For the gels incubated at 30 °C, the rheometer showed higher sensitivity compared to folding test. On the other hand, the gels incubated at 60 °C exhibited the higher agreement between rheometer results and sensory test. The phenomenon is also the same for the standard rheometer. Obviously, folding test can reflect gel degradation very efficiently, which generally occurs at 60 °C in fish paste (Kinoshita et al. 1990).

As mentioned above, the rheometer manufactured here is equal to the standard one available in the market, although its utilization is limited to puncture test only. However, it would be possible, to measure not only the elastic properties of various fish and meat gels but also those of other foods, if the shape of the plunger and sample stage, or the movement of the table stage are devised. What is important is that the production cost of this instrument is about one eightieth of the existing price of a commercial rheometer.

Conclusion

A simplified rheometer was constructed to measure the textural properties of various fish and meat gels, like kamaboko, ham, hampen and sausage. Mechanical force applied to the gel through the penetration of a ball type plunger was recorded directly with a chart recorder. The gel quality of various food gels prepared in the Laboratory and obtained from the market was measured using this rheometer. The data thus obtained were verified through folding and sensory scores of the products. Instrumental results maintained a strong correlation with corresponding folding and sensory scores. To examine its degree of accuracy the gel quality measured by the simplified rheometer was compared with that by a commercial rheometer commonly used in Japanese kamaboko testing system. Correlation coefficients between the results of two rheometers were highly significant, indicating the ability of the simplified rheometer to produce authenticated data.

Acknowledgment

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