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Effect of the Physical Properties of Food on the Recognition of Particles and the Distinguishable Size Range of the Particles in the Mouth

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The smallest recognizable particle size of foods in the mouth and the size range of distinguishable particles were examined sensorily for different food samples. These two factors were evaluated in relation to the physical properties of the food samples.

Samples in the form of aqueous suspensions were prepared from nine pulverized food materials by passing them in water through standard sieves which resulted in a geometrical size ratio of approx. 1.19.

The smallest recognizable particle size, which depended largely on the material, was least in cellulose (34μm) and most in 1% agar gel (380μm). Excepting *hanpen* and bread, food particles differing in size by 1.2 times on average were distinguishable when the particle size was above a certain level (the smallest distinguishable particle size). The smallest distinguishable particle size depended on the food material.

The smallest recognizable particle size and the smallest distinguishable particle size were associated with such physical properties of the materials as the water content, the deformation coefficient, and the density.

The smallest recognizable particle size and the smallest distinguishable particle size were subjected to a multiple-regression analysis to express them numerically by using the physical properties of each material. The smallest recognizable particle size and the smallest distinguishable particle size could be expressed by multiple-regression equations with the deformation coefficient *etc.*

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INTRODUCTION

Many types of food are made up of groups of particles of various sizes or composed of particles which are dispersed in a liquid. For instance, cooked granular meat and boiled rice are groups of large particles, while *dango* (pounded rice cakes) and *anko* (bean paste) are in the group of particles ranging from tens to hundreds of micrometers. Potage also consists of particles dispersed in water of less than 1μm to hundreds of μm across. Particles thus play an important role by characterizing a food and contributing to its physical properties and taste quality. In some foods, a certain level of particle size is required for good taste quality. *Dango* (Katsuta 1987) and *anko* (Yajita *et al.* 1972) comprising particles of approx. 100-150μm are both more desirable than when comprising larger or smaller particles. In *miso* soup with soybean grains (Okuda *et al.* 1987), the soup with about 25% of particles over 150μm had a smoother texture and was more desirable than that with about 40% of the same particle size, but the soup with about 10% of the same particle size was too smooth to be desirable. On the other hand, chocolate (Rostagno 1969) and ice cream (Fukushima and Kimura 1992) become undesirable when particles can be perceived in the mouth. Therefore, it is useful to examine the smallest particle size that a person can recognize and the smallest difference in particle size that a person can distinguish, particularly when these examinations can be related to the physical properties of a food.

Other than the above-mentioned foods, several

studies on peanut butter (Muego *et al.* 1990), margarine (Vaisey-Genser *et al.* 1989), fondants (Woodruff and Gilder 1931), soups (Moteki and Yamamoto 1987; Matsumoto and Mineki 1981; Yoshizawa 1984), and bean paste products (Su and Chang 1995) have examined the preparation conditions with the object of obtaining the most desirable particle sensation for each product, although none of these studies made a general investigation into the relationship between the sensation from the particle size and the physical properties of the food.

There have also been some dentistry studies on the recognition of substances in the mouth. Kawamura (1976) has reviewed that the minimum particle size of metal foil perceivable by the teeth was 20-30 μm for sensitive people and 100 μm for insensitive people. Teeth could also distinguish a difference in the thickness of synthetic resins as small as 0.18 mm when the mouth was open 5 mm wide (Manly *et al.* 1952). The threshold value for distinguishing the diameters of two steel wires was 0.2 mm for wires less than 3 mm in diameter, and 0.3 mm for wires more than 4 mm in diameter, with a Weber ratio of 0.1 for complete distinction (Kawamura and Watanabe 1960). These studies used metals for the tests and were limited to the sensation by the teeth.

A pharmacological study (Tyle *et al.* 1990) has examined the mouth feeling by using several types of sample with different physical properties. In that experiment, three particle sizes each of three types of material were dispersed in a liquid to evaluate the texture in five steps from "smooth" to "gritty." The hardness and shape of each sample depended on the material used. The study concluded that the hard and angular materials became gritty as the particle size increased, while soft, spherical materials and flat, somewhat hard materials remained smooth regardless of the particle size. Since the study employed only the "hardness" as a physical property and the particle size ranged only to a small extent, however, it was not a systematic examination on the particle size and physical properties of materials.

The object of this study is to investigate sensorily the mouth feeling, particularly the smallest size which can be recognized as a particle and the distinguishable range of particle size, by using particles from tens of μm to 1 mm, which represents the range of particle size found in foods, and to examine which physical properties of foods have an effect on the particle sensation.

MATERIALS AND METHODS

Materials

An aqueous suspension of each sample was used because a dry powder markedly changes its physical properties when it mixes with saliva in the mouth. Eight materials were selected for the following reasons: 1) they undergo no physical change such as dissolution after the sample has been prepared; 2) it is practicable to prepare particles of around 20-1,000 μm in size; 3) they are uniform materials, having the same composition with different particle sizes; 4) they are available in a wide range of physical and geometrical properties. The eight materials selected were albumin (first grade reagent, flakes made from egg, Wakojunyaku Kogyo), casein (reagent, made from milk, Kantokagaku), agar (powder, Wakojunyaku Kogyo), *shirataki* (noodles made from devil's tongue starch, Shimonitake), cellulose (microcrystalline type, average particle size of 20-700 μm, Asahi Kasei Kogyo), *tofu* (fine-grained type, Sunshop Yamazaki), bread (loaf cut into eight slices, Yamazaki Seipan), and *hanpen* (fish cake, Kibun Foods). Each of these materials was prepared into uniform samples with a particle size in the 20-1,000 μm range, which were free from changes in physical properties such as dissolution after the sample had been prepared. The different particle sizes caused no difference in the components of the materials.

Sample preparation

Albumin was heated in boiling water for 5 min, and after changing the water a few times to remove the odor, the residual water was removed at 105℃ for 5 h in a drier. The resulting dry material was crushed with a grinder, and the resulting powder was added to water and allowed to soak overnight.

Casein was crushed with a grinder, and the resulting powder was added to water and allowed to soak overnight.

Agar gel (1%) was prepared by adding about 600 g of distilled water to 5 g of agar powder, allowing it to swell for 1 h, heating while stirring for 30 min to dissolve and boil down to 500 g, cooling to room temperature, and leaving at 20℃ overnight. The resulting gel was cut into approx. 3-cm cubes, supplemented with water and pulverized with a mixer (NMX-0701, Koizumi Seiki).

Agar gel (2%) was prepared in a similar way and pulverized with the mixer.

Shirataki was heated in boiling water for 1 min and then pulverized with the mixer.

Cellulose was added to water and allowed to soak overnight.

Tofu was added to water and pulverized with a cooking cutter (CQ-30(A), Toshiba).

Each slice of bread with the crust removed was cut into four pieces, and the moisture was removed at 105 ℃ for 30 min in a drier. The dried bread was pulverized (Konahikisan SK-1800, Yamamoto Denki Kogyo) and added to water for soaking.

Hanpen was cut into approx. 3-cm cubes, added to water, and pulverized with the mixer.

Each of these nine materials, after being well soaked and pulverized, were passed through standard sieves (JIS) in water. These standard sieves were of 23 types ranging from 23 to 1,000 μm in mesh size with a geometrical size ratio of about 1.19. Each resulting suspension was poured into a 100-ml tall beaker and left for about 1 h. The supernatant was discarded to obtain about 200 types of sample with a particle content of 30-50% (w/w).

Aqueous suspensions were used for the sensory evaluation, and the particles were removed from the samples for physical property measurements.

Particle size and geometrical characteristics

An optical or stereo microscope was used to take pictures of the samples, and a SIP: IMC-512V8 color-image analytical processing device with the SPECTRUM image analyzer program (Mitani Shoji) was used to determine the area of about 100 particles, the diameter (assuming a circular form), the degree of circularity, the volume, the maximum length, the lengths of the long and short axes, and the ratio between the long and short axes.

The diameter (assuming a circular form) is referred to as the particle size for each sample.

Water content

Since the water content was presumed to be the same among different particle sizes, particles of approx. 400-600 μm were chosen from each material. The water content was measured by the heat-drying method at 105℃ under normal pressure by using plastic film (diatom-earth addition film method, Nihon Shokuhin Kogyo Gakkai Syokuhin Bunsekiho Henshu Iinkai (Food Analysis Editorial Committee of Japanese Society for Food Science and Technology) 1982).

Density

The density was also presumed to be the same among different particle sizes, so particles of approx. 200-400 μm were chosen from each material. The density was measured by the liquid immersion method by a pycnometer (Funtai Kogakkai (Society of Power Technology) and Nihon Funtai Kogyo Gijutsu Kyokai 1985).

Precipitation test in water

A small amount of particles was dropped into water (20℃) filling a glass tube (5 cm in diameter and 1 m in height), and the time was measured for the particles to precipitate from a point 20 cm down from the top to a point 50 cm further down. With the agar gels, a stop watch was used to measure the time, while for the experiments with the other samples, a videotape was recorded for later analysis of the precipitation time.

Particles of more than 500 μm were used because measurement was difficult for smaller particles.

With each sample, 15-40 particles were used for measuring the precipitation rate (cm/s).

Compression test

A Rheorobot (KA300PV precision type, Kyowa Seiko) was used for the compression tests. The load-cell plunger mounted on the upper part of the device was lowered on to a particle placed on the measurement plate, and after determining the height of the particle, a load was applied to the particle. The Rheorobot digitally detects the load on the particle and the change in particle height with time. The load cells used were 2 kgf, 100 gf, or 2 gf, depending on the material being tested, while the plunger was 2 mm in diameter, and the loading rate was 467 μm/min, 40-50 particles being measured for each material.

Sensory evaluation

1. Particle recognition test

Approx. 0.1 % vanilla essence was added to each sample to minimize the effect of odor. A sample of approx. 1 ml was placed on an approx. 2-ml plastic spoon, which was then placed on a small plate to serve to each panelist. Each panelist put the entire sample into the mouth, and used the tongue and the roof of the mouth to determine whether the particles dispersed in the sample could be recognized as such. After doing this, the sample was spat out and the mouth rinsed with distilled water.

A panelists did not recognize particles if the sample was perceived as being a smooth, uniform, and continuous liquid without any particle sensation. The panelists were also instructed not to recognize particles, even when they felt something other than pure water, if they could not perceive the presence of a sized particle.

The data were treated by the probit method, and the particle size at which 50% of the panelists recognized particles is designated as the minimum

Table 1. Values for the physical properties of each material

	DC[a]	WC[b]	DE[c]	P-C[d]	$\bar{k}_1$[e]	$\bar{k}_2$[e]
1% agar gel	0.691	99.3	1.022	1.25	4.96	1.73
2% agar gel	0.367	98.2	1.007	1.26	4.70	1.74
Albumin	0.725	79.2	1.052	1.2	5.43×10^{-3}	1.38×10^{-3}
Bread	0.638	86.2	1.079	0.64	3.07	1.33
Casein	0.714	70.8	1.077	1.04	7.14×10^{-2}	3.12×10^{-2}
Cellulose	0.884	49.7	1.231	1.13	2.50×10^{-3}	2.13×10^{-3}
Hanpen	0.295	91.1	1.087	1.15	5.14	1.69
Shirataki	0.580	95.9	1.019	1.78	3.75	1.57
Tofu	0.741	91.9	1.035	1.06	3.97	1.74

[a] Degree of circularity. [b] Water content (%). [c] Density (g/cm^3). [d] Precipitation rate-particle size coefficient. [e] Deformation coefficient.

recognizable size of the particles.

2. Particle size distinction test

The paired distinction method was used to determine whether two different particle sizes for each material were distinguishable. A pair of samples were served to each panelist, the particles of one of the pair being about 1.19 times larger than the other. The samples were prepared in the same way as that used for the particle recognition test in paragraph 1. The two samples were served in the same right-and-left position to half of the panelists, and similar samples were served in the opposite position to the other half of the panelists.

Each panelist put one of the samples in the mouth and used the region around the incisor papilla at the anterior of the hard palate, which has acute ability (Suzuki 1994; Arai and Yamada 1993), and the tongue to recognize particle size. After doing this, the sample was spat out and the mouth rinsed with distilled water. The panelist then put the other sample in the mouth in the same way to determine which sample had the larger particles.

The binomial test was used for analyzing the results.

Sensory evaluations of both the particle recognition test (paregraph 1 above) and the particle size distinction test (paragraph 2 above) were conducted in individual compartments of a sensory evaluation room under red light to make the samples less visually distinguishable. These evaluations were conducted from 10:00 to 11:30 a.m., 1:00 to 3:00 p.m., and 5:00 to 6:00 p.m. The panelists were 20 members of the Cookery Science Laboratory of Ochanomizu University ranging in age from 21 to 25.

Statistical treatment

Excel ver. 5.0 for Macintosh (Microsoft) was used for the regression analysis, and Statistica ver. 4.1 for Macintosh (Statsoft) was used for the correlation and multiple-regression analyses. SPSS 6.1J for Macintosh (SPSS Japan) was used for the probit method.

RESULTS AND DISCUSSION

Since some of the particles in our samples were as small as tens of μm and comprised various components and shapes, it was difficult to accurately measure physical properties. In order to examine the effect of the physical properties of a food on the mouth feeling, however, we tried to obtain the physical properties of particles in as objective a way as possible.

Physical properties

Table 1 lists the degree of circularity, water content, density, precipitation rate-particle size coefficient, deformation coefficients $\bar{k}_1$ and $\bar{k}_2$ for each material.

1. Degree of circularity

The eight parameters for the geometrical characteristics that were measured with the image processing device were examined to determine which expressed most accurately the shape of a material. Cellulose and *hanpen* resulted in outstanding pictures: the particles of cellulose were almost completely circular, while those of *hanpen* were mostly amorphous and looked like clumps of filaments or stark trees covered with ice. The difference was reflected more in the degree of circularity than in any other parameter. The degree of circularity was calculated as the value of $4\pi\times$area/circumference^2. With this formula, the degree of circularity of a perfect circle is

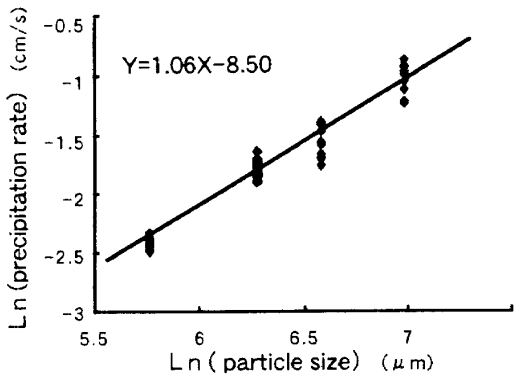

Fig. 1. Relationship between the precipitation rate and particle size for *tofu*

1. Provided that the area is the same, the degree of circularity approaches 0 as the circumference increases. The degree of circularity was thus employed to express the particle shape of each sample. Since the degree of circularity did not depend on the particle size, the degree of circularity for each material was calculated as the average of all particle samples of the same material.

Cellulose had the largest degree of circularity at 0.884, while *hanpen* had the smallest at 0.295, the values for the other materials being in the range of 0.58-0.74. In this way, the difference in shape was found to be an objective measurement.

2. Water content

Cellulose had the lowest water content at 49.7%, followed by casein at 70.8%. The water content was mostly over 80% for the other materials, most of them thus having an extremely high water content.

3. Density

Cellulose had the highest density at 1.23 g/cm^3, the others ranging from 1.01 g/cm^3 for the 2% agar gel to 1.09 g/cm^3 for *hanpen*. Broadly speaking, the materials with the lowest density had an extremely high water content, although albumin and *tofu* had very different water contents in spite of their similar density. Casein, bread and *hanpen* also had different water contents, but had similar density.

4. Precipitation rate-particle size coefficient

In general, larger particles precipitate faster in a given liquid if the particle density is the same, and if the density increases, so does the ratio of the change in the precipitation rate to the change in the particle size (Kousaka 1987), that is, the precipitation rate-particle size coefficient in our experiment (refer to Fig. 1).

The complex shapes and structures of the materials. however, mean that the density cannot be simply assumed to be associated with the precipitation rate in our experiment. As just one of the physical properties of each material, the precipitation rate of particles in water was measured.

Figure 1 shows the relationship between the precipitation rate and the particle size of *tofu*. Like the case of *tofu* shown in Fig. 1, the other materials also had increasing precipitation rate with increasing particle size, although there was some variance. However, the ratio of the change in the precipitation rate to the change in the particle size depended largely on the material. In order to clarify the difference among materials, a regression analysis was made concerning the precipitation rate and the particle size for each material to obtain a regression line. The regression slope is designated as the precipitation rate-particle size coefficient, which is one of the characteristic values for each material.

The results are shown in Table 1. The coefficient was largest in *shirataki* (1.78) and smallest in bread (0.64). The others had the coefficient in the range of 1.04-1.26.

No high correlation was found between the precipitation rate-particle size coefficient and the density. This possibly resulted from the complex physical properties of the particles in our experiment.

The precipitation rate-particle size coefficient, however, is useful in our experiment as an index of the physical properties of each material.

5. Deformation coefficient

The compression test measured the particle height and the change in the applied load with time. The original height of all particles was different, so the change in particle height was divided by the original height to obtain the strain (ε, %), which was then used to obtain a load-strain curve for each particle. Figure 2 shows the load-strain curve for one particle of each of the nine samples.

As is shown in Fig. 2, the load-strain curves for almost all the particles monotonically increased without any fracture point. This monotonic increase was presumably caused by the moistness of the particles which underwent gradual compression rather than a sudden fracture under a given load. Therefore the fracture strength, which is generally given by fracture or compression tests, was not obtained in this experiment. Neither was Young's modulus obtained because of the unpredictable continual change in the cross section of the particles.

We attempted to express the load-strain curves by one equation. Trial and error produced an ex-

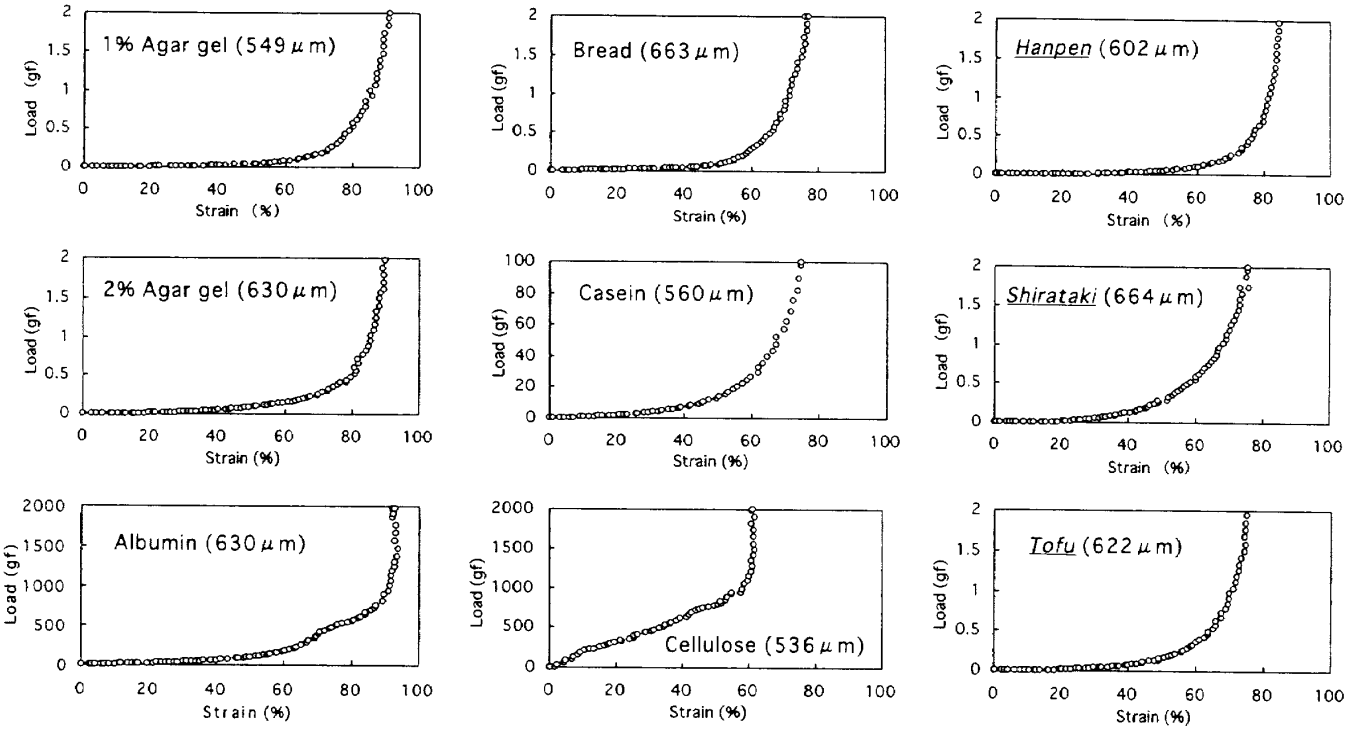

Fig. 2. Load-strain curve for each particle

ponential function, in which the logarithm of strain was roughly proportional to the load. In the process of obtaining this exponential function, the inspection of each load-strain curve resulted in the following observations:

1) As is shown in Fig. 2, the strain of almost all the particles did not reach 100 % and was likely to have a finite limit (ε_∞). This limit for each particle seems to have been approximately the same for the same material.

2) The starting point (ε_0) of the curve varied with particles even in the same material. This variation in ε_0 is attributable to the varied shape of each particle, which caused the particles to start to resist compression at different times.

Our experiment can be expressed by the following Kuno equation (Kubo *et al.* 1985):

$$\varepsilon_\infty - \varepsilon = (\varepsilon_\infty - \varepsilon_0)\, e^{-kf}. \quad [f = \text{load}] \qquad (1)$$

This exponential equation is generally used in engineering to give the material characteristics for compression filling or tamping filling.

We decided to use the exponential equation because it applies well to ε_∞ and ε_0 of our compression experiment, considering that the sample particles of our experiment are made up of even finer particles. In Eq. (1), k is a constant which allows for the factors of shape and size of the particles; the shapes of all the particles were different from each other and cannot be expressed numerically. In addition, the cross section changed continually under compression and cannot be expressed numerically or by an equation, either.

ε_0, ε_∞, and k were obtained from the load-strain curve for every particle. ε_0 was the starting point of the curve and was read from the graph, which agreed with the strain under a load of about 1% of the total load. ε_∞ was calculated to have the largest correlation coefficient between $\ln(\varepsilon_\infty - \varepsilon)$ and f (load). The value of k was then obtained as the slope of the regression equation.

Equation (1) was a straight line dropping to the right with slope k, when plotted with $\ln(\varepsilon_\infty - \varepsilon)$ for the Y-axis and f for the X-axis. This equation is sometimes shown as a curved line instead of a straight line (Hayakawa *et al.* 1973).

Figure 3 is an example of the results of our experiment. As is shown in Fig. 3, many particles resulted in curved lines instead of completely straight lines.

The value for slope k_i was obtained for each curved line. k_i is termed the "deformation coefficient" because it shows the resistance to the deformation of the samples at stage "i."

When k_i was obtainted for every particle of each of the materials, many of the particles produced k_1, k_2, and k_3, which are composed of three curved lines.

Some samples with relatively short particles resulted only k_1, and others had k_1 and k_2. Among the nine materials, many particles of albumin had k_1, k_2, k_3 and even k_4. Although the ideal value for k_3 should approximate to 0, that is, parallel to the X-axis according to Eq. (1), k_3 in our experiment tended to be larger than k_2 as is shown in the figure. This may be attributable to the small number of measuring points and the scatter of the measurements, which would be more likely to influence k_3 than k_1 or k_2. Further investigation of this should be made in another study.

This study used k_1 and k_2, which are thought to show the deformation resistance in the first and second stages. For each material, k_1 values had a large scatter and k_2 values had a small scatter. Excepting k_1 for cellulose, k_1 and k_2 for each material

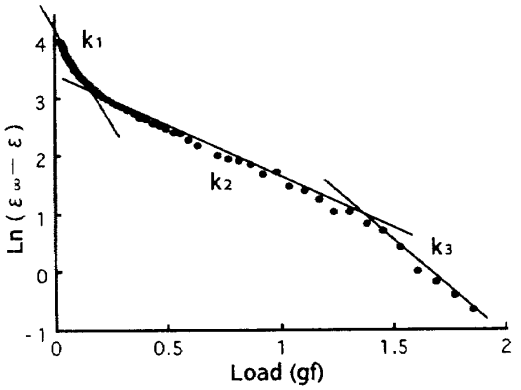

Fig. 3. Relationship between the load and $\ln(\varepsilon_\infty - \varepsilon)$ for the 2% agar gel

ε_∞ is the limiting value for strain (ε).

were independent of the height of the particles. Consequently, the average values for k_1 and k_2 of each material expressed as $\bar{k}_1$ and $\bar{k}_2$ as shown in Table 1.

$\bar{k}_1$ was larger than $\bar{k}_2$ for every material. Both $\bar{k}_1$ and $\bar{k}_2$ were very small in the order of cellulose, albumin and casein, while $\bar{k}_1$ and $\bar{k}_2$ for the other six materials were about 50 times wore than those for the first three materials just mentioned. Among the six materials, $\bar{k}_2$ was about the same (1.33-1.74), but $\bar{k}_1$ (3.07-5.14) varied according to the material.

Sensory evaluation

1. Smallest recognizable particle size

The smallest recognizable particle size resulting from the sensory evaluation is shown in Fig. 4. The value depended largely on the material, cellulose having the smallest value at 34 μm, followed by albumin at 43 μm, casein at 61 μm, *hanpen* at 160 μm, bread at 219 μm, 2% agar gel at 299 μm, *tofu* at 320 μm, *shirataki* at 351 μm, and 1% agar gel at 380 μm.

The smallest recognizable particle size is compared with the physical properties in Table 1. Cellulose, albumin and casein, which had extremely small values for the smallest recognizable particle size, had a markedly lower deformation coefficient and water content than the other materials. *Shirataki*, *tofu*, 1 % agar gel, and 2 % agar gel, which had large values of more than about 300 μm for the smallest recognizable particle size, had higher water content and lower density than the other materials. Between the materials having large values of more than 300 μm for the smallest recognizable particle size and those materials having medium values for the smallest

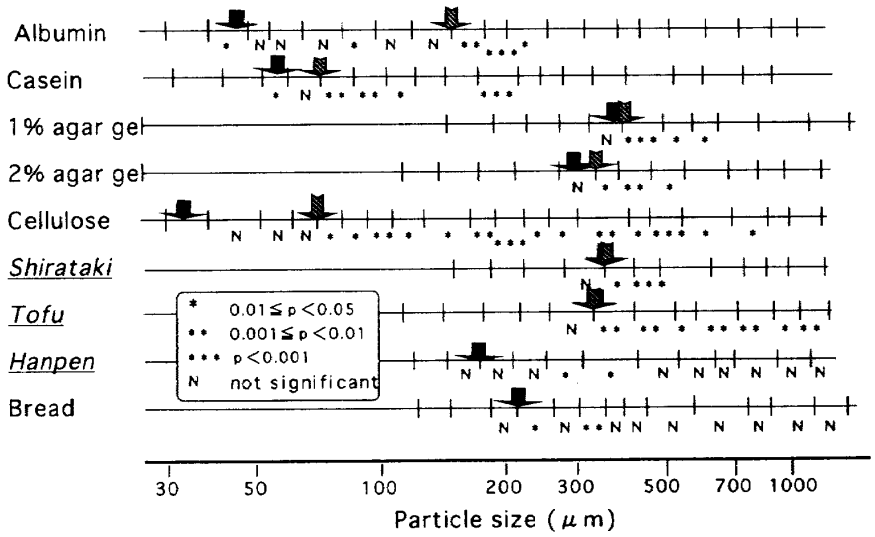

Fig. 4. Results of the sensory evaluation

⬇, smallest recognizable particle size; ⇳, smallest distinguishable particle size.

recognizable particle size (*hanpen* and bread), there was no specific relationship between the deformation coefficient and the precipitation rate-particle size coefficient. In all the materials, there was no specific link between the smallest recognizable particle size and the degree of circularity.

In our experiment, the smallest particle size recognizable by the mouth was therefore found to be related to such physical properties as the water content, the deformation coefficient, and the density of the material.

In connection with foods requiring smoothness, several studies have examined the particle size so that the foods can be considered as smooth. No one could perceive particles of approx. 8 μm across in chocolate, but a small percentage of people could perceive particles of approx. 13 μm across (Cook 1982). The tongue could perceive particles in chocolate when 20% or more of the crystals of cocoa butter were over 22 μm (Rostagno 1969). The smallest particle perceivable by the roof of the mouth was found to be around 25 μm in size (Hinton 1970). Most chocolate products are considered smooth if the crystals are less than 25 μm (Bernard 1980). Fondants are considered smooth if the maximum particle size of the crystals is 19.5 μm, but the crystals could be perceived if they were over 25.5 μm in size (Woodruff and Gilder 1931). Crystals in margarine could be perceived when they were over 22 μm in size (Vaisey-Genser *et al.* 1989).

These values are close to that of cellulose in our experiment, although our value was slightly larger. This difference probably resulted from the fact that our panelists were trained not to recognize particles when they could not sense the substance size, even if they felt something like grittiness due to a substance dispersed in the sample.

The physical properties of the particles were thus found to have the greatest influence on the smallest recognizable particle size.

2. Distinguisable size range of particles

In addition to the smallest recognizable particle size for each material, Fig. 4 also shows whether the particle size could be distinguished between two samples of different particle sizes, one of which was 1.19 times the size of the other.

Excepting *hanpen* and bread, the samples of different particle size could be distinguished when the particles were above a certain critical size. They could not, however, be distinguished up to the critical size, which depended on the material. This critical point is designated as the smallest distinguishable particle size and is shown in Fig. 4.

In the general relationship between stimulus and sensation, $\Delta R/R$ (Weber ratio) is constant when stimulus R of a moderate degree is distinguishable from ΔR. In our experiment, the particle size of one of the compared samples was around 1.19 times that of the other, which means that the Weber ratio was around 0.19. Our experimental results show that the Weber ratio for particle size distinction was not more than 0.19 above a certain critical point. However, the Weber ratios for *hanpen* and bread were found to be more than 0.19, which suggests that the Weber ratio for particle size distinction was influenced by the difference in physical properties of the food materials.

Referring to the Weber ratio for various sensations, the figure for the sensation of taste is 0.15-0.25, which is said to be larger than that for the sensation of touch or weight (Sato 1991). The Weber ratio is 0.003-0.088 for the sensation of sound, 0.136 for that of pressure, 0.016 for that of lightness, 0.200 for that of taste, and 0.104 for that of smell (Tasaki and Ogawa 1989). A Weber ratio of 0.1 was found necessary to completely distinguish the difference in size of substances by biting with the teeth (Kawamura and Watanabe 1960). Therefore, the Weber ratio for distinguishing particle size is thought to be larger than that for the sensation of sound or vision, probably smaller than that for the sensation of taste, and approximately equal to that for the sensations of smell, pressure, and biting with the teeth.

Two samples differring in particle size by 1.19 times were not distinguishable for *hanpen* and bread. The reason for this can be proposed in respect of the physical properties shown in Table 1. The relevant factor may have been the particle shape of *hanpen*, which appeared in the form of filaments or stark trees covered with ice, having the smallest degree of circularity among the materials. Bread, on the other hand, had the smallest precipitation rate-particle size coefficient among the materials. The porous structure of bread, which was not evident in the degree of circularity, may have influenced the precipitation rate in water. The reason for the undistinguishable particles differing in size by 1.19 times may thus be attributable to the effect of the shape or internal structure of *hanpen* and bread.

The smallest distinguishable particle size was 73 μm for casein, 78 μm for cellulose, 156 μm for albumin, 317 μm for *tofu*, 355 μm for the 2% agar gel, 359 μm for *shirataki*, and 397 μm for the 1% agar gel. The

Table 2. Correlation matrix of physical property values

Variable	1	2	3	4	5
DC[a] 1					
WC[b] 2	−0.52				
	−0.80				
DE[c] 3	0.30	−0.91			
	0.85	−0.95			
P-C[d] 4	−0.12	0.28	−0.31		
	−0.72	0.44	−0.35		
k_1[e] 5	−0.58	0.85	−0.57	0.19	
	−0.53	0.87	−0.68	0.38	
k_2[e] 6	−0.51	0.86	−0.61	0.18	0.98
	−0.55	0.87	−0.68	0.40	0.99

[a]–[e] *cf.* Table 1. Upper figure: correlation coefficient for the smallest recognizable particle size. Lower figure: correlation coefficient for the smallest distinguishable particle size.

smallest distinguishable particle size tended to increase as the smallest recognizable particle size increased. Therefore, the smallest distinguishable particle size is thought to have been influenced by the physical properties of each material which also affected the smallest recognizable particle size. As far as the results of our experiment are concerned, the relevant physical properties were the water content, the deformation coefficient, and the density of the material.

Smallest recognizable particle size and smallest distinguishable particle size expressed numerically by the physical properties of the particles

Since the smallest recognizable particle size and the smallest distinguishable particle size perceived in the mouth were found to depend largely on the material, a multiple-regression analysis was applied to express these factors numerically by such physical properties of a material as the water content, the deformation coefficient, and the density.

Prior to this multiple-regression analysis, a coefficient analysis was made between the physical properties of the materials, with the results shown in Table 2. The upper column in Table 2 shows the correlation matrix when using the nine materials for the smallest recognizable particle size, and the lower column shows the correlation matrix when using the seven materials for the smallest distinguishable particle size. According to Table 2, the explanatory variables chosen for the multiple-regression analysis were the physical properties which are deemed to have been independent of each other. The explanatory variables for the smallest recognizable particle size were the four factors of the degree of circularity, density, precipitation rate-particle size coefficient, and $\bar{k}_1$ value. The explanatory variables for the smallest distinguishable particle size were the three factors of the degree of circularity, precipitation rate-particle size coefficient, and $\bar{k}_1$ value. The dependent variables were the smallest recognizable particle size and the smallest distinguishable particle size. The multiple-regression analysis by the stepwise method ($F_{in}=F_{out}=1$) resulted in the following multiple-regression equations and multiple-correlation coefficients (R), with the partial standard regression coefficient shown in parentheses:

Natural logarithm of the smallest recognizable particle size
$=0.39\ \bar{k}_1-4.1$ density$+1.5$ (degree of circularity)
(0.89**) (−0.29) (0.26)
$+7.2$ $R=0.96^{**}$.
(*)

Natural logarithm of the smallest distinguishable particle size
$=0.28\ \bar{k}_1+0.52$ (precipitation rate-particle size
(0.87**) (0.18)
coefficient) $+4.0$ $R=0.95^{**}$.
(**)

** $p<0.01$, *** $p<0.001$.

The smallest recognizable particle size was expressed clearly by the equation involving the deformation coefficient, density and degree of circularity. The smallest distinguishable particle size was expressed by the equation involving the deformation coefficient and precipitation rate-particle size coefficient.

These results provide important information for examining the relationship between the physical properties of a food sample and the feeling of food particles in the mouth.

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REFERENCES

Arai, E., and Yamada, Y. (1993) Effect of the Texture of Food on the Masticatory Process, *Shika Kiso Igakkai Zasshi* (*Jpn. J. Oral Biol.*), **35**, 312-322

Bernard, W. (1980) *Minifine, Chocolate, Cocoa and Confectionery: Science and Technology*, Avi. Publishing Co., Westport, Connecticut, 117, 649

Cook, L. R. (1982) *Chocolate Production and Use*, Harcourt Brace Jovanovich, New York, 177

Fukushima, M., and Kimura, T. (1992) *Miruku Sogo Jiten* (ed. by Yamauchi, K., and Yokoyama, K.), Asakura Shoten, Tokyo, 88

Funtai Kogakkai (Society of Power Technology) and Nihon Funtai Kogyo Gijutsu Kyokai (1985) *Funtai Bussei Zusetsu*, Nikkei Gijutsu Tosho, Tokyo, 41

Hayakawa, S. (1973) *Funtai Bussei Sokuteiho*, Asakura Shoten, Tokyo, 110

Hinton, C. J. (1970) *Twenty Years of Confectionery and Chocolate Progress* (ed. by Pratt, C. D., de Vadetzsky, E., Langwill, K.E., McCloskey, K. E., and Schuemann, H. W.), Avi. Publishing Co., Westport, Connecticut, 111

Katsuta, K. (1987) Effects of Composition and Mixture (Glutinous and Nonglutinous) of Rice Powder on Evaluation of Sensory Attributes of "Dango" (in Japanese), *Nihon Kasei Gakkaishi* (*J. Home Econ. Jpn.*), **38**, 711-718

Kawamura, Y. (1976) Oral Function Regarding Recognition of Physical Properties of Food (in Japanese), in *Shokuhin no Bussei* (ed. by Matsumoto, S.), Shokuhin Shizai Kenkyukai, Tokyo, 85-98

Kawamura, Y., and Watanabe, M. (1960) Studies on Oral Sensory Threshholds: I The Discrimination of Small Differences in Thickness of Steel Wires in Persons with Natural and Artificial Dentitions, *Med. J. Osaka Univ.*, **10**, 291-301

Kousaka, Y. (1987) *Hunryutai Kogaku* (ed. by Kagaku Kogaku Kyokai), Maki Shoten, 88-89

Kubo, K., Jinbo, M., Mizuwatari, E., Takahashi, H., and Hayakawa, S. (1985) *Funtai Riron to Oyo*, Maruzen, Tokyo, 342

Manly, R.S., Pfaffman, C., Lathrop, D.D., and Keyser, J. (1952) Oral Sensory Thresholds of Persons with Natural and Artificial Dentitions, *J. D. Res.*, **31**, 305-312

Matsumoto, E., and Mineki, M. (1981) Food Histological Studies on the Soup of Green Peas (Part 1) (in Japanese), *Nihon Chori Kagaku Kaishi* (*J. Cookery Sci. Jpn.*), **14**, 183-187

Moteki, M., and Yamamoto, S. (1987) Influence of Mashing Treatment on Sensory Attributes of Creme Vichyssoise Glacee (in Japanese), *Nihon Chori Kagaku Kaishi* (*J. Cookery Sci. Jpn.*), **20**, 130-136

Muego, K.F., Resurreccion, A.V.A., and Hung, Y-C. (1990) Characterization of Texture Properties of Spreadable Peanut Based Products, *J. Texture Studies*, **21**, 61-73

Nihon Shokuhin Kogyo Gakkai Shokuhin Bunsekiho Henshu Iinkai (Food Analysis Editorial Committee of Japanese Society for Food Science and Technology) (1982) *Shokuhin Bunsekiho*, Korin, Tokyo, 10-15

Okuda, K., Osada, Y., and Ueda, R. (1987) The Effect of Miso Soup Preparation Procedures on Particle Size Distribution (in Japanese), *Nihon Chori Kagaku Kaishi* (*J. Cookery Sci. Jpn.*), **20**, 210-214

Rostagno, W. (1969) Chocolate Particle Size and its Organoleptic Influence, *The Manufacturing Confectioner for May 1969*, 81-86

Sato, M. (1991) *Mikaku no Seirigaku*, Asakura Shoten, Tokyo, 4

Su, H. L., and Chang, K. C. (1995) Physicochemical and Sensory Properties of Dehydrated Bean Paste Products as Related to Bean Varieties, *J. Food Sci.*, **60**, 794-797

Suzuki, T. (1994) *Kiso Shika Seirigaku* (ed. by Sakata, S., and Nakamura, Y.), Ishiyaku Shuppan, Tokyo, 295

Tasaki, K., and Ogawa, T. (1989) *Shin Seiri Kagaku Taikei* (*9*) *Kankaku no Seirigaku*, Igaku Shoin, Tokyo, 2-3

Tyle, P., Kuenn, C., Geier, L., and Jarosz, P. (1990) Effect of Size, Shape and Hardness of Particles in Suspension on Oral Palatability, *Drug. Dev. Ind. Pharm.*, **16**, 1339-1364

Vaisey-Genser, M., Vane, B. K., and Johnson, S. (1989) Graininess, Crystal Size, and Firmness of Stored Canola Oil Margarines, *J. Texture Studies*, **20**, 347-361

Woodruff, S., and Gilder, H. V. (1931) Photomicrographic Studies of Sucrose Crystals, *J. Phys. Chem.*, **35**, 1355-1367

Yajita, T., Nakajima, K., and Tsuboya, M. (1972) Size Distribution of Bean Paste and Physical Properties of Sweet Bean Paste (Part 4) (in Japanese), *J. Niigata-ken Shokuhin Sogo Kenkyusho*, **12**, 31-37

Yoshizawa, M. (1984) Effects of Mixing Rice Powder with Wheat Flour on the Viscosity and the Texture of a Cream Soup (in Japanese), *Nihon Kasei Gakkaishi* (*J. Home Econ. Jpn.*), **35**, 833-838

ogo Kenkyusho, **12**, 31-37

Yoshizawa, M. (1984) Effects of Mixing Rice Powder with Wheat Flour on the Viscosity and the Texture of a Cream Soup (in Japanese), *Nihon Kasei Gakkaishi* (*J. Home Econ. Jpn.*), **35**, 833-838

Mouth Feeling of the Food Particles with the Different Physical Properties

口腔における粒子の認識と粒度の識別におよぼす食品物性の影響

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口腔内で食品粒子を粒子として認識する際の最小粒度および粒子の大きさの識別の程度について官能的に明らかにし，さらにそれらと食品物性との関係を検討した．細砕した9種類の食品材料を約1.2倍の等比間隔にある標準ふるいを用いて水中でふるい分けし，試料（水懸濁液）とした．認識最小粒度は，セルロースの34 μmが最小で，最大は1％寒天ゲルの380 μmであり，材料によって著しく異なった．また粒度の識別の程度は，はんぺんとパン以外は，ある粒度以上において平均1.2倍異なる粒度の識別ができること，また，そのある粒度（識別最小粒度とする）は材料によって異なることが明らかになった．以上の認識最小粒度および認識最小粒度は，材料の物性値のうち水分含量，変形定数および密度等の物性値と関係が深いと考えられた．そこで認識最小粒度と識別最小粒度を，材料の物性値を用いて数値化することを重回帰分析を用いて試みたところ，それぞれ変形定数などを用いた重回帰式で表すことができた．

キーワード：官能評価，食品物性，食品粒子，粒子径．