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Introduction

Rice has been the main food in Japan and has supported approximately sixty percent of calorie in the production of domestic agricultural products. Owing to the fact that the rice is fundamentally produced once a year in Japan and that the crop situation is greatly affected by annunal weather, the crop of rice changes annually. In 1993 we recorded one of the poorest crops of rice brought about by a cold weather, the crop situation index being one of the worst numbers of 74. With the Japanese government not having sufficient stock of rice in that year, the market of rice was driven into a sort of short supply. In order to improve the sordid situation of 'lack of rice', some amounts of foreign countries' rices were imported as an emergency aid. The rices were mainly imported from U.S.A., China, Thailand and Australia in 1993 and many of them were different from the domestic ones in shape, quality, physical and chemical properties. For an example, rice produced in U.S.A. is mostly long in shape and cooking method of rice is of great difference between U.S.A. and Japan. In American long sized rice is commonly parboiled and then fried, and these are used as side dishes like a dish of cooked potato. In Japan, a boiling of rice is to be carried out in accordance with the traditional cooking method. When the foreign countries' rices with different varieties and properties were boiled in the same manner as in case of Japanese one, it would be impossible to keep the same taste and characteristics of Japanese rice cooked by boiling process. It is quite natural that consumers should feel deep embarrassments for sudden import of foreign countries' rices, on the other hand, the rice processing industrial world, the eating out industrial world, and electric rice boiling machine makers, are alike quite perplexed about the necessity of taking new measures to meet the suddenly befallen situation. It was considered to be quite important for us to understand the properties and characteristics of foreign countries' rices which seems to be on the way of increasing in future.

We have had a miserable experience of 'lack of foods' immediately after the world war II. There were naturally a great deal of 'lack of rice', which made it necessary to import rice from foreign countries. In those days, the imported rice was mostly a sort of long sized rice from California in U.S.A., the partly short sized rice being imported from Taiwan. There was a difference of taste between the domestic and the imported rices. National Food Research Institute belonging to Ministry of Agriculture, Forestry and Fisheries was interested in the difference in the taste derived from the variety of rice, and the different characteristics of boiled rice were considered to be due to a difference of starch in rice. The trial to investigate the different characteristics by variety of rice was attempted by measuring viscosity and elasticity of the pasted rice starch. It was the first step to these series of studies about the taste of rice[6]. Nowadays, acknowledgement of the emergency import of the foreign countries' rice caused by a worst crop harvest in 1993 and the partial acceptance of the imported rice by making Japanese markets of agricultural products open, have taken place, and the studies for safety, taste and properties of the imported rices have been put on the way[1,5,7,8,9].

The purpose of this study is to obtain some basic data concerning the physical properties for the rice imported from foreign countries and the water absorption characteristics of rice in cooking process. In the study of the water absorption characteristics of rice, changes of moisture content and water absorption rate under various soaking hours, and temperatures were investigated, and water absorption distribution in one kernel rice was measured and analyzed.

Materials and Methods

1. Materials

The rices imported from California state in U.S.A., north-eastern part of China, Thailand and Australia, and the Japanese rice (Nigata pref.) were used in this experiment. Long sized rice was imported from Thailand in the form of polished rice. Medium sized rice was imported from U.S.A. and Australia in the form of brown rice. Short sized rice was imported from China in the form of brown rice. In order to be constant in measuring conditions, all of the rices were polished three times by the standard polishing machine (Satake Co. Ltd.) and the non-cracked rice was selected in this experiment.

2. Measuring of physical properties of rice

The physical properties (shape, whiteness, cracking rate, moisture content and hardness) were measured in all kinds of rice. The rice shape was measured in major length, miner length and height by a vernier micrometer. The whiteness of rice was measured by a difference colorimeter (Minolta, CR-200). The hardness of rice was measured at the breakdown and crashing points by a tensiron meter. The moisture content and the cracking rate of rice were measured by the standard methods[3].

3. Measuring of chemical properties of rice

The chemical properties of rice were measured by a near infrared (NIR) method. The general taste meter (TB15A) with infralyzer 500S (Satake Co. Ltd.) was used as a NIR instrument. The NIR method was developed as a simple measuring method for analyzing the chemical components of food and agricultural products[2]. Amirose, protein and fatty acid contents of rice were measured in this experiment. As the taste values were not the absolute ones like chemical analyzing values, they were measured as a sort of reference to the quality evaluation of rice.

4. Measuring of water absorption characteristics of rice

The characteristics of water absorption playing a part as a basic factor in cooking was measured in all kinds of rice. Fig. 1 shows an experimental apparatus for measuring of water absorption characteristics of rice. At first, the water absorption rate and quantity of rice were measured in water bath under fixed water temperatures holding 20, 30 and 40℃. A rice sample of approximately 20g was weighed by a electric precise balance and it was soaked in the water bath during fixed hours. Sample was taken out at every fixed hours, and its weight was measured by the electric precise balance after being strained off the water from the sample. The sample was strained off the water by a kitchen strainer for approximately one

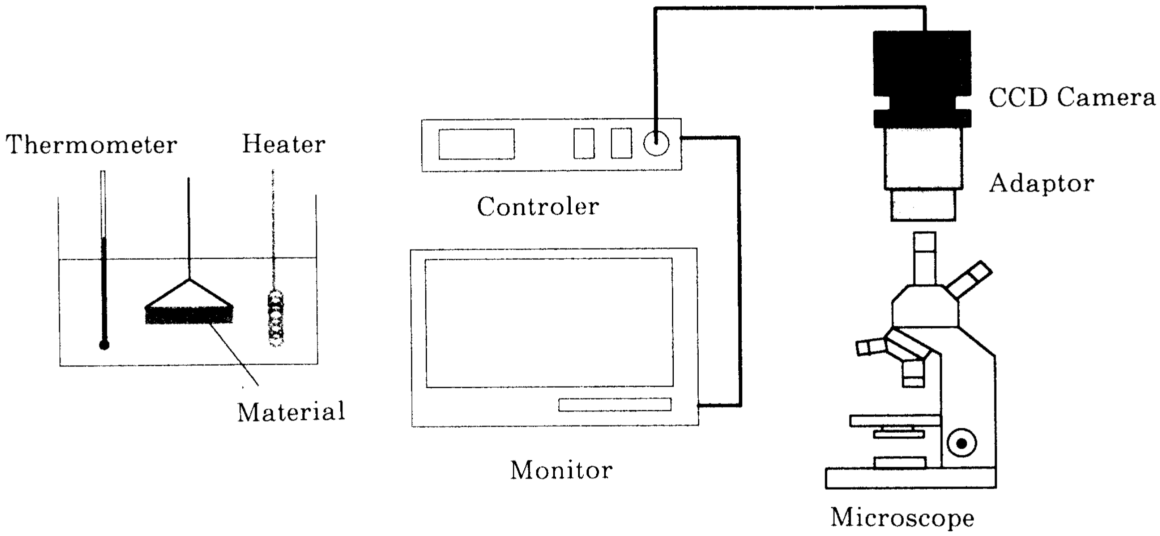


Fig. 1. Schematic diagram of experimental apparatus.

minutes after having been softly wiped out with a gauze. A rice with water absorption was weighed with five minutes interval, until the first thirty five minutes, on account of its rate being so fast. Afterwards, it was weighed with thirty minutes interval until reaching 125 minutes. As Japanese rice reached approximately saturated absorption weight in thirty minutes in the pre-experiment, the measuring interval time was also adopted for other imported rices. After testing, a bone dry weight of rice was measured at the drying condition of 105℃ for twenty four hours, and the moisture content of rice was calculated.

In the experiment of water absorption model, the water absorption distribution in one kernel rice was observed by a microscope. A sample was soaked in water bath under a constant temperature, and the sample was taken out at every fixed hours and after having softly wiped out the water, and cutting the center of one kernel rice, the diameter of the water penetrated inside of one kernel rice and the expansion diameter of the rice were measured by the microscope. It was measured at the temperatures of 20, 30 and 40℃ in the water bath. Sample selection was made out of the rices shaped same in major length, miner length and height of one kernel rice, and all the measurements were carried out on the assumption that every sample was the same kernel rice in this experiment. In order to make a clear observation of the internal water absorption of a rice by the microscope, a food rouge was dissolved in the water at a fixed density. Using the microscope monitor magnified by approximately 100 times, the measurements were carried out at every five minutes.

Results and Discussions

1. Physical properties of various kinds of rice

Physical properties of various kinds of rice were investigated in shape, crack rate, moisture content, whiteness, hardness and chemical components. Fig. 2 shows the rice shapes in U.S.A., China, Thailand and Japan. As rice imported from China was the short sized rice, its shape was completely as same as the Japanese one. California rice imported from U.S.A.

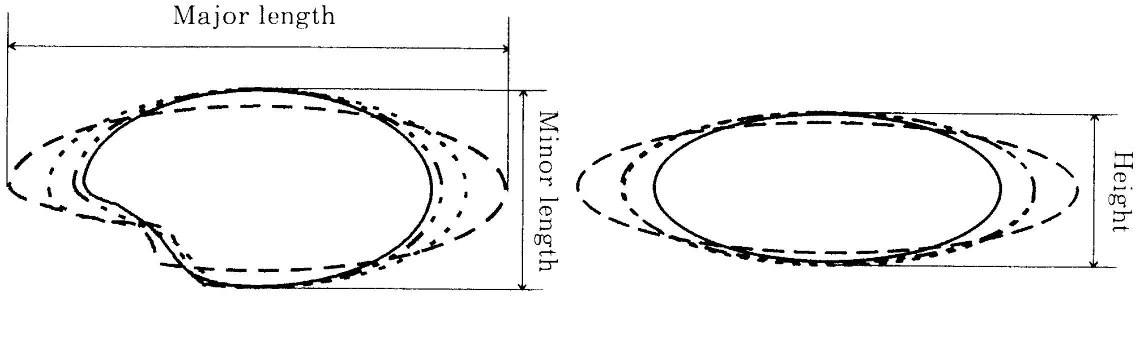


Fig. 2. Shapes of various rices.

was medium sized rice and the height and miner length in the shape were approximately as same as Japanese one, but the major length in the shape was a little longer than Japanese one. Rice imported from Thailand was a long sized rice, and the height and miner length of the rice were shorter than Japanese one and the major length of the rice was longer than Japanese one. Judging from the shape of rice, it was clear that the rice imported from Thailand was greatly different from the other ones.

Table 1 shows basic physical properties of rice. Ratio of cracked rice, a thousand rice

Table 1. Characteristics of various rice

	U.S.A.	China	Thailand	Australia	Japan
Ratio of cracked rice (%)	13.5	3.0	5.0	18.0	3.5
A thouthand rice weight (g)	22.96	22.00	19.74	22.63	23.00
Moisuture content (%)	15.1	16.2	11.9	13.8	14.8
Whiteness	55.8	54.7	50.1	—	53.3
Breakdown hardness (kg)	7.1	5.0	6.4	8.2	5.6
Crashed hardness (kg)	11.5	8.0	10.1	10.6	8.0

weight, moisture content, whiteness and hardness of rice were measured. The ratio of cracked rice was higher in the rices imported from U.S.A. and Australia, being lower in those imported from China and Thailand. It was considered to be due to the fact that rices imported from U.S.A. and Australia were dried by a heat dryer and those imported from China and Thailand were dried by sunlight. A thousand rice weight was the same excepting those from Thailand. Moisture content of rice was higher in the rice imported from China and lower in those imported from Thailand and Australia, comparing with the standard moisture content (14.5-15.5% w.b.) in Japan. The rice imported from China in 1993 partially contained musty one. It was considered to be due to the high moisture content. As the rice imported from Thailand was in the situation of polished rice, it was of the lowest moisture content. Whiteness of rice was lowest in the rice imported from Thailand and other ones were the same in whiteness. Hardness of rice was measured in breakdown and crashing points of rice. Both the breakdown and crashing hardness were lower in the short sized rice from China and in Japan but there was no clear difference between the medium sized rice from U.S.A. and from

Australia and the long sized rice from Thailand in hardness. It was ascertained that the short sized rice was softer than the medium and long sized ones.

The chemical components of rice were analyzed by NIR method, and the results are shown in Fig. 3. Amirose, protein, moisture and fatty contents of the rice were measured, and the

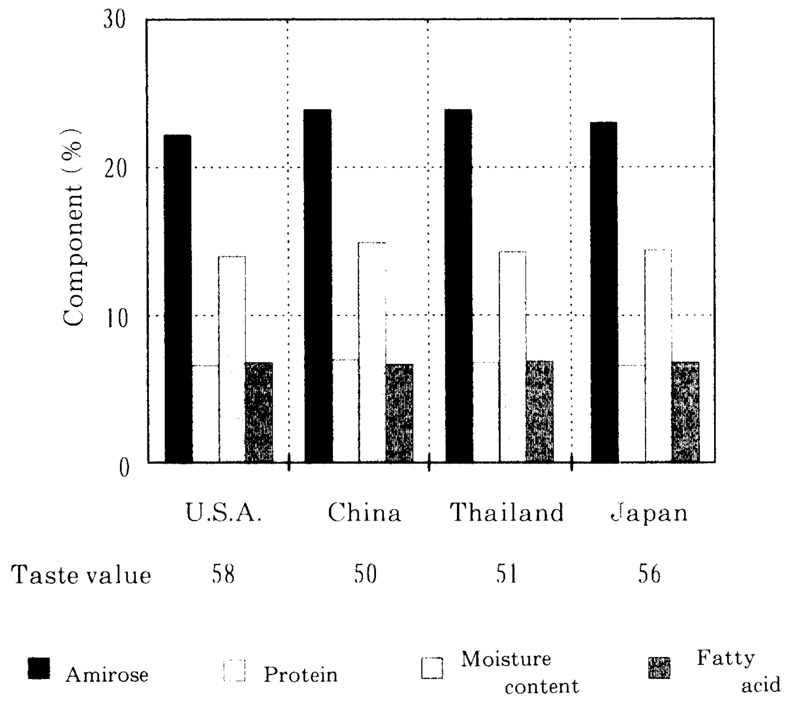


Fig. 3. Analysis of chemical components of rice by NIR method.

taste value is indicated as a total result index in Fig. 3. The taste value was apt to rise at the occasion, when moisture content and whiteness of rice were high, and it was apt to fall at the occasion, when amirose content was high. Main chemical component of rice was amirose content, and there was no clarified difference in protein and fatty acid contents among the rices of the respective countries. The amirose content of rice was higher in the order of China, Thailand, Japan and U.S.A.. There was no ascertained difference in chemical components of rice by NIR analysis, among the short, medium and long sized rices. The taste value was higher in the order of U.S.A., Japan, Thailand and China. Although the rice imported from China contained with moisture content, its taste value was lowest.

2. Water absorption characteristics of rice

It is quite important to understand the water absorption characteristics of the polished rice during the boiling process. In this experiment, the water absorption characteristics of various kinds of polished rice were investigated. The changes of rice weight were measured in the condition of being soaked in water bath under a fixed water temperature, in order to investigate the change of moisture content of the polished rice in water soaking. The water temperatures were adopted at 20, 30 and 40℃ in this experiment, and the measuring of the weight of rice was carried out with five minutes interval until the first 35 minutes, and with 30 minutes interval until 125 minutes.

Fig. 4 shows the changes of moisture contents of each country's polished rice in water

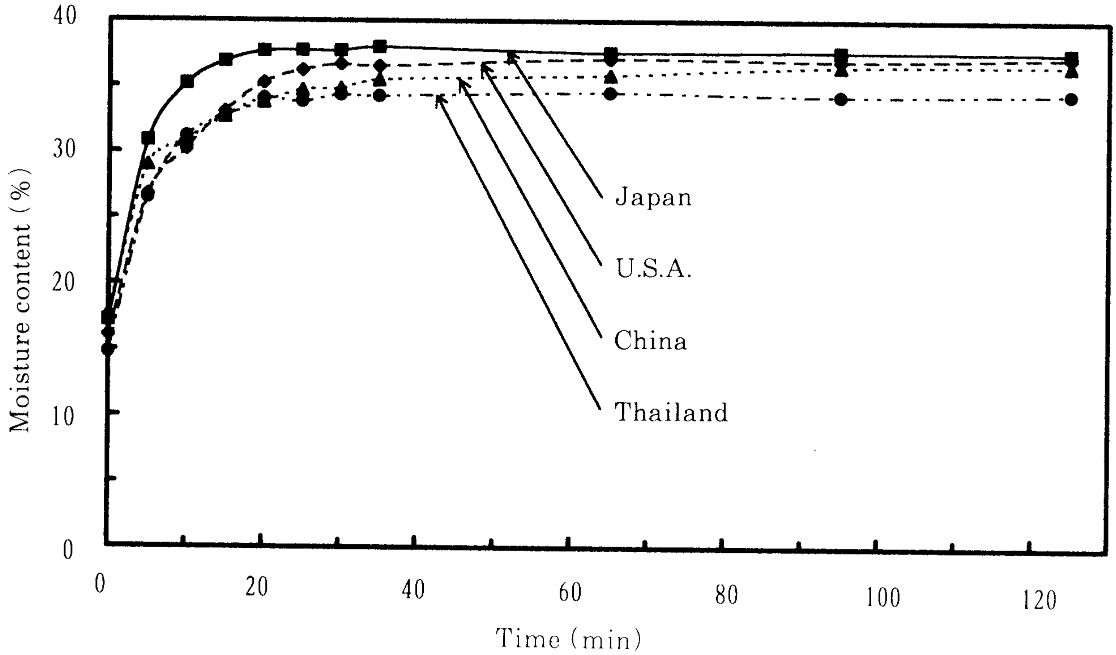


Fig. 4. Change of moisture content of rice.

soaking at the temperature of 40℃. The moisture contents of each country's polished rice were saturated for approximately 30 minutes after being soaked in water, and all of the moisture contents of rice excepting those of Thailand showed the same value after 125 minutes in water soaking. As there were differences of moisture contents in each country's rice, it was obvious that the water absorption characteristics were different among the respective countries' rices. The moisture content of Japanese rice increased faster than those of the other countries' rices during 30 minutes from the beginning. The moisture contents of polished rice were 37.7% w.b. in case of the one in Japan, 36.6% w.b. in case of the one from U.S.A., 34.8% w.b. in case of the one from China and 34.3% w.b. in case of the one from Thailand after 30 minutes soaking in water, and there was no difference in the changes of moisture contents among the other countries' rices including short, medium and long sized rices. These changes of moisture contents of rice were apt to be similar at the water temperatures of 20 and 30℃. Judging from the change of moisture content in Fig. 4, Japanese rice could be boiled after 15 minutes soaking in water but in other countries' rices, it was necessary for them to be soaked in water for more than 2 hours before the boiling. Especially, in order to increase the saturated moisture content of the rice imported from Thailand, it was considered to be necessary under the condition of being soaked in water to adopt some pre-managements with a special processing method.

The changes of water absorbance of rice were investigated, and the calculation was made by a ratio of actual moisture content to the moisture content after 125 minutes under a apparent equilibrium condition. The effect of water temperature on water absorbance of rice is shown in Fig. 5. The water temperatures of 20, 30 and 40℃ were adopted and the Japanese rice was used in this experiment. The water absorbance of rice increased with the increasing of water temperature during the first 30 minutes of soaking in water, and the water

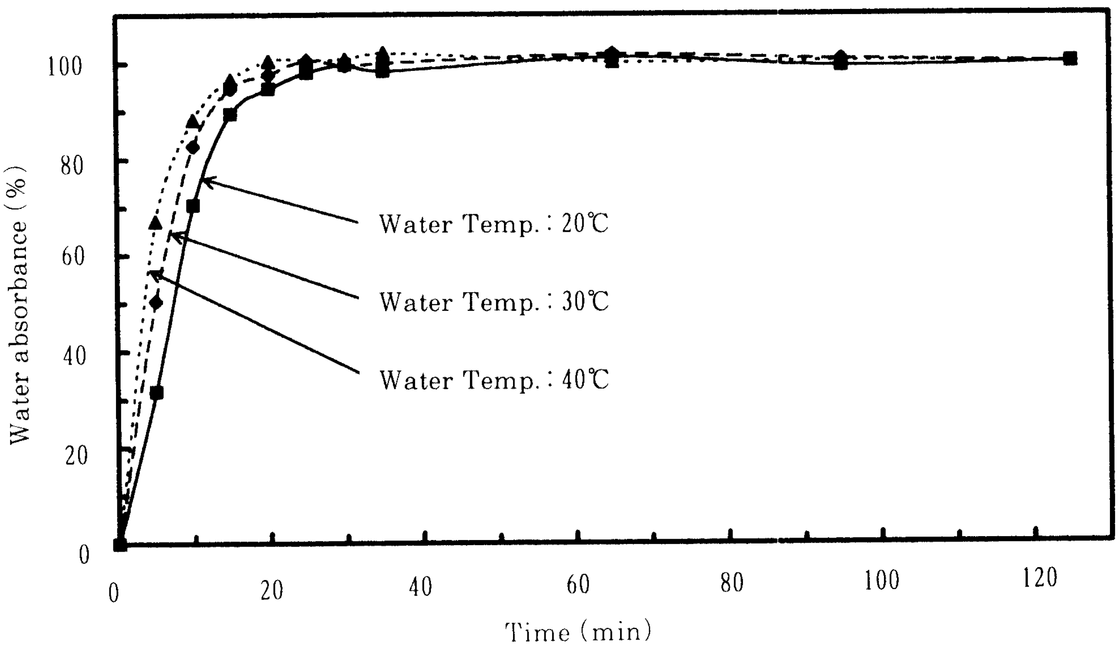


Fig. 5. Change of water absorbance of Japanese rice.

absorbances of rice under any water temperatures were close to roughly 100% after approximately 30 minutes of soaking in water. Therefore, the effect of water temperature on water absorbance of rice was clearly observed during the first 30 minutes of soaking in water, and the higher was the water temperature, the faster was the water absorbance rate. The water absorbance rates of the other rices showed similar tendencies.

Fig. 6 shows the changes of water absorbances of rices produced in Japan, imported from

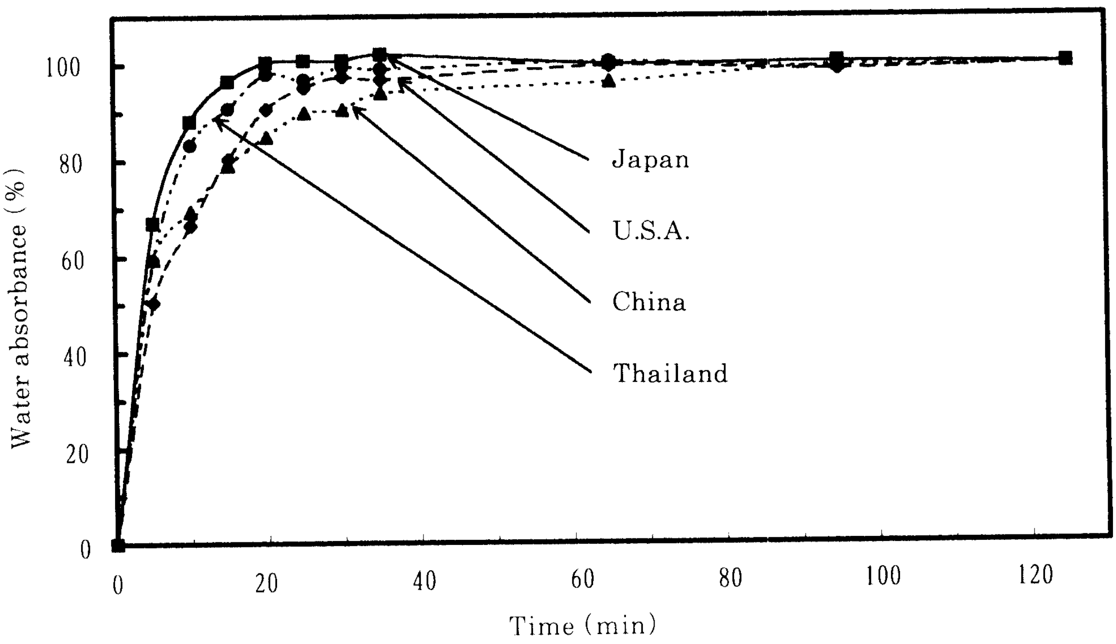


Fig. 6. Change of water absorbance.

U.S.A., China and Thailand, and these rices were tested under the condition of being soaked in water at the temperature of 40℃. The water absorbances of rice in Japan and from Thailand reached roughly 100% after 30 minutes of soaking in water. The water absorbances of rice from U.S.A. and China reached roughly 100% after 65 minutes and 95 minutes of soaking in water, respectively. The water absorbances showed big differences among the respective countries' rices, especially, until the first 30 minutes of soaking in water. The water absorbance rates of rice increased in the order of Japan, Thailand, U.S.A. and China. The saturated moisture content of the rice imported from Thailand was lower than those in the other countries' ones, but the water absorbance rate was faster than those excepting in case of Japan. The water absorbance rates were faster in the order of long, medium and short sized rices excepting Japanese one. Japanese rice was ascertained to be different from the other countries' ones in water absorption characteristics. The results about water absorbances at the water temperatures of 20 and 30℃ showed a tendency similar to the result obtained at water temperature of 40℃.

Consequently, it was ascertained that as the saturated moisture content of Japanese rice was highest and the water absorbance rate of Japanese rice was fastest, Japanese rice was the best one in boil cooking.

3. Mathematical model of water absorption

In order to analyze the water absorption characteristics of rice during soaking in water, a mathematical model of water absorption was proposed concerning the early stage soaking in water. The mathematical model is shown as follows;

$$\mathbf{X}(\theta,\mathbf{t}) = (\alpha + \beta \cdot \theta) + (\gamma + \delta \cdot \theta) \cdot \mathbf{LN}(\mathbf{t})$$

θ: Soaking time in water (min)

t: Soaking temperature in water (℃)

α, β, γ, δ : Coefficients of water absorption model

The mathematical model expressed the water absorption of rice as a function of soaking time and temperature in water. In the mathematical model, coefficients of β and δ were related to the soaking time in water and coefficients of γ and δ were related to the soaking temperature in water. These coefficients were calculated concerning rices in Japan, from U.S.A., China and Thailand. The calculated results of the respective coefficients are shown in Table 2. Comparing with coefficient of δ which was related to the soaking time and temperature in water, the value of Japanese rice was the highest and the value of rice imported from Thailand was the lowest. The δ coefficient of rice imported from Thailand was of an extremely small value and it was considered to be due to the fact that the rice imported from Thailand was long sized one. The other coefficients of the rice imported from Thailand also showed a different tendency, comparing with the other coefficients of the rices in Japan, from

Table 2. Coeffcients of water absorption model of rice

	α	β	γ	δ
Japan	33.029	−0.111	0.734	0.734
China	28.057	−0.056	− 9.609	0.436
U.S.A.	25.999	0.066	−17.957	0.520
Thailand	−11.418	0.463	35.171	−0.016

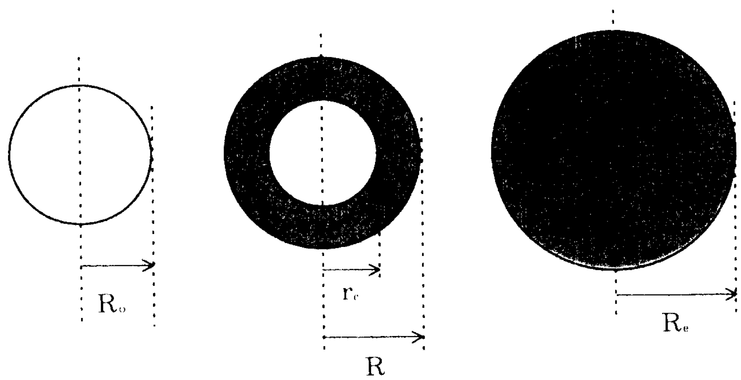
U.S.A. and China. The coefficient of β was related to the soaking time in water and it was lower in the order of Japan, China, U.S.A. and Thailand. It was ascertained that there was no clear difference between the short sized rice imported from China and the medium sized rice imported from U.S.A..

Consequently, it was clearly confirmed that water absorbance of Japanese rice was to be saturated in the shortest time and at the lowest temperature of soaking in water, judging from the coefficients of water absorption in the mathematical model.

4. Water absorption distribution in one kernel rice

In order to investigate the water absorption distribution of rice, measuring of the moisture transfer was tried at the inside of one kernel rice. One piece of kernel rice was soaked in water colored with a food rouge during a fixed time under a constant temperature. The water absorption distribution at the inside of a colored rice was observed by magnifying it with a microscope. The moisture was diffusely absorbed at the inside of the rice, though expanded somewhat by water absorption process. Therefore, one kernel model was put under consideration of the expansion and water absorption were measured at the one piece of kernel rice.

Fig. 7 shows schematic model of the expansion and water absorption of one kernel rice. The water absorption process is expressed by the change of radius of one kernel rice. R_0, R_e, R and r are initial radius, final radius, expansion radius and absorption radius, respectively.



R_0 : Initial radius

R : Expansion radius

r_c : Absorption radius

R_e : Final radius

Fig. 7. Change of radius of one kernel rice in absorption model.

Fig. 8 shows the change of expansion and absorption radius of one kernel rice under the soaking in water. The expansion and absorption radius were measured at four points in cross section of central position of rice and were expressed by an average value. The measurements were carried out about all kinds of rice and the results of Japanese rice are shown in Fig. 8. The expansion radius, R, slightly increased and the absorption radius, r, gradually decreased. The moisture transfer in the direction of radius was found to have reached to the center of rice after approximately 95 minutes. In case of the short sized rice imported from China, R and r changed as similarly as in case of Japanese rice but the moisture transfer was found to

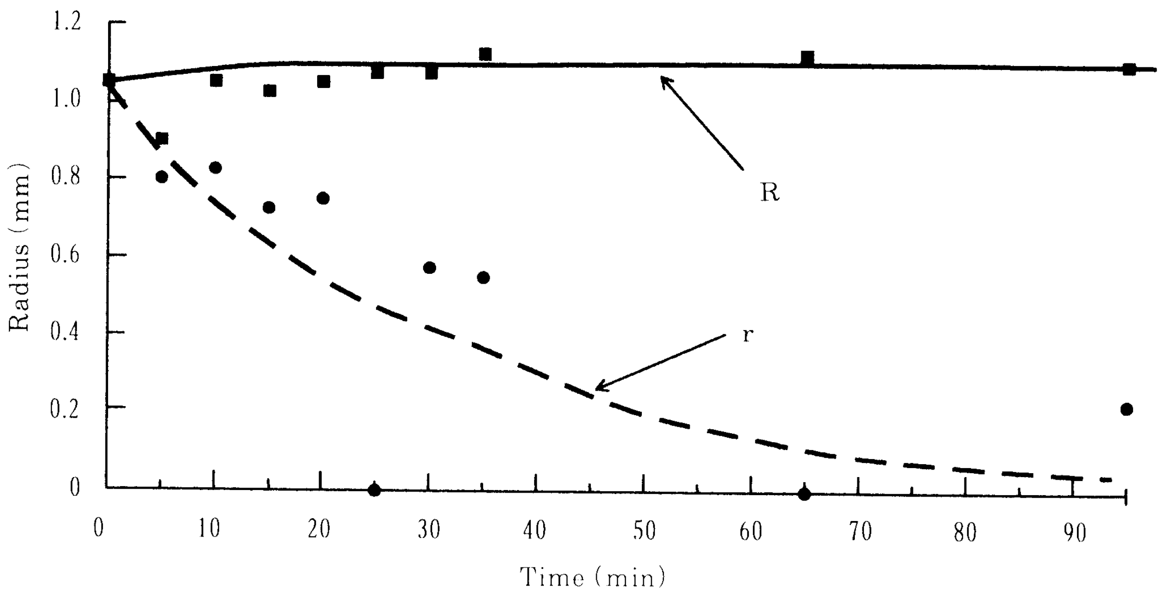


Fig. 8. Change of radius of one kernel rice in soaking.

have finished after 120 minutes. In case of the medium sized rice imported from U.S.A. and in that of long sized rice imported from Thailand, R changed as similarly as in that of Japanese rice but the change of absorption radius was different. The moisture transfer did not finish during the measuring time of 120 minutes and stopped at 50 or 40% of a radius after approximately 40 minutes from the beginning. It was shown that the short sized rice perfectly absorbed the moisture and medium or long sized rice did not perfectly absorb the moisture. In Fig. 8, these data were fixed to have included a sort of nuevenness but to have formed same sorts of curves. Therefore, the mathematical models were assumed in accordance with these curves and are shown as follows;

$$\mathbf{R = a + b \cdot LN}\,(\theta)$$

$$\mathbf{r = c \cdot exp}\,(\mathbf{d} \cdot \theta)$$

where, R : Expansion radius

r : Absorption radius

θ : Soaking time in water

a, b, c, d : coefficients

The mathematical models were solved by experiment data and the results of Japanese rice were as follows;

$$\mathbf{R = 1.0178 + 1.323 \times 10^{3} \times LN}\,(\theta)$$

$$\mathbf{r = 1.3382 \times 10^{4} \times exp}\,(\mathbf{0.4209}\,\theta)$$

The expansion radius and absorption radius of one kernel rice are to be predicted, using these mathematical models[4]. Assuming that a rice is of a cylindrical shape, the mathematical model of water absorption of one kernel rice is shown as follows;

$$\mathbf{dX/d\theta = \{2\pi \cdot r \cdot L\,(C_e - C_i)/(Y_e - Y_i)\}/\{r \cdot LN\,(R/r)/K_m + 1/K_r\}}$$

where, C_i : Initial moisture content (%)

C_e : Equilibrium moisture content (%)

Y_i : Initial weight of a rice (g)

Y_e : Equilibrium weight of a rice (g)
L : Major length (mm)
X : Water absorbance (%)
K_m : Parameter of diffuse rate in moisture transfer
K_r : Parameter of water absorption rate in diffuse surface
R : Expansion radius (mm)
r : Absorption radius (mm)

Using these experimental data, these parameters K_m and K_r are to be calculated. The parameter K_m and K_r of Japanese rice are shown as follows;

$$\mathbf{K_m = 1.443 \cdot \times 10^{4}}$$

$$\mathbf{K_r = 0.0274}$$

It was very difficult to get precise experimental data because the rice was very small and same size, shape and property of rice were not to be selected. There was much unevenness in the data, but depending on the calculation of these parameters of other countries' rices, the water absorption characteristics of every country's rice may be known in details.

Consequently, it is possible to estimate water absorption and moisture transfer in one kernel rice by using these parameters and coefficients calculated with these mathematical models.

Summary

In order to investigate the physical properties and water absorption characteristics of the rices imported from foreign countries, the shape, crack rate, moisture content, whiteness, hardness, water absorbance and so on were measured. The short, medium and long sized rices were selected in this experiment. The short sized rice was imported from China. The medium sized rice was imported from U.S.A. and Australia. The long sized rice was imported from Thailand. The difference between these countries' rices and Japanese rice was discussed.

In physical properties of rice, the crack rate of rice was high at the ones from U.S.A. and Australia and moisture content of rice was high at the one from China and low at the one from Thailand. The whiteness of rice was high at the one from U.S.A. and low at the one from Thailand. Hardness of rice was high at the one from U.S.A., Thailand and Australia, and low at those from China and in Japan. There were some difference among the respective countries' rices but no difference was found among the short, medium and long sized rices in this experiment.

In order to understand the water absorption characteristics of the polished rice during the boiling process, the water absorption characteristics of various kinds of the polished rice were investigated. At first, the changes of moisture contents and water absorbance of the respective countries' polished rices soaked in water at the various temperatures were investigated. It was ascertained that as the saturated moisture content of Japanese rice was the highest and the water absorbance rate of Japanese rice was the fastest, Japanese rice was the best one in boil cooking.

In order to analyze the water absorption characteristics of rice during soaking in water, a mathematical model of water absorption was proposed. It was clearly ascertained that water absorbance of Japanese rice was saturated in the shortest span of time and at the lowest temperature of soaking in water, judging from the coefficients of water absorption in

mathematical model.

In order to investigate the water absorption distribution in rice, measuring of the moisture transfer was tried at the inside of one kernel rice. In analyzing of the experimental data, depending on the fact that the water absorption process is to be expressed as the change of radius of one kernel rice, some mathematical models were considered. The expansion radius and absorption radius of one kernel rice were to be predicted, using these mathematical models. Assuming that a rice is of a cylindrical shape, the mathematical model of water absorption of one kernel rice was to be made easily. It was possible to estimate water absorption and moisture transfer in one kernel rice by making use of these parameters and coefficients calculated by these mathematical models.

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