Effects of the rice polishing ratio on water absorption of rice

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要旨：米は清酒の主原料であり、その特性は酒づくりに大きな影響を与える。特に米の吸水特性は蒸米の硬軟を左右し、もろみの発酵状態に多大な影響を及ぼすこととなる。これは、高品質な清酒を製造するためには、米の吸水特性を十分把握しコントロールすることが不可避であることを示している。

本研究は、原料米の吸水特性を解析することを目的としている。特に、精米歩合を変化させることによる吸水への影響を明らかにすることを目指した。その手法は、原料米の吸水曲線を数値化し、その特性を吸水方程式のパラメータとして抽出するものである。考案した手法の有用性を確認するために、著名な 2 品種である良食味米の日本晴と酒米の五百万石に限定して比較検討することとした。検討の結果、両品種ともに 50～90% の精米歩合において S 字型に湾曲した吸水曲線を表したが、日本晴より五百万石で湾曲率が高くなる傾向が認められた。個別の品種特性を確認したところ、日本晴では高精米歩合で湾曲率が高くなったが、五百万石では高精米歩合と低精米歩合ともに湾曲率が高くなった。これらの現象の要因として、米粒内部の成分分布や酒米に特徴的な心白構造の影響が考えられた。

Abstract: Rice is the main ingredient in sake, and characteristics of rice strongly influence the process of sake production. In particular, water absorption characteristics of polished rice affect hardness of the rice when it is steamed, which strongly affects the properties of *moromi,* the main fermenting sake mash. Thus, for the production of high-quality sake, specialists need a good understanding of and control over the water absorption characteristics of rice.

In this work, we analyzed the water absorption characteristics of rice as a raw material, particularly focusing on the influence of the rice polishing ratio on water absorption. To this end, we constructed water absorption curves and used the data to solve an absorption equation. To confirm the utility of our method, we compared 2 well-known products: the table rice strain Nipponbare and the brewing rice strain Gohyakumangoku. We obtained S-shaped water absorption curves for both strains, with rice polishing ratios of 50–90%. The curvature tended to be sharper for Gohyakumangoku. Although Nipponbare yielded a sharp curve only at a high polishing ratio, Gohyakumangoku yielded a sharp curve at both high and low polishing ratios. The distribution of components within the rice grain and the characteristic *Shinpaku* structure of the brewing rice appear to be the main factors behind this phenomenon.

Key words: 原料米 rice　吸水特性 absorption characteristics　精米歩合 rice polishing ratio　数式化 modeling　醸造 sake brewing

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Introduction: Sake production begins with the processing of whole-grain rice into polished rice, with a rice polishing ratio appropriate for a finished product. After the processing, rice is allowed to absorb water. The rice is then steamed, after which approximately 20% is used to make *koji*-rice, to which yeast is added; the remaining 80% is used in the fermentation process. Therefore, the water absorption process is a highly important part of the early stages of sake production.

Because of this importance, extensive research has been conducted on the absorption of water by rice. Kumagai and coworkers previously studied water content, the rate of water absorption, and enzyme digestibility of steamed rice; those authors showed that these properties are closely related[1)]. Yanagiuchi and colleagues analyzed water absorbency and found differences between different strains of rice used as raw materials[2)]. In addition, Yoshizawa and Hanamoto assessed the influence of rice-soaking temperature on fermentation[3, 4)].

We have also analyzed the reaction kinetics of water absorption by rice using mathematical modeling[5, 6)]. The utility of this strategy has been demonstrated, and its use has resulted in many important findings: Kubota and coworkers analyzed kinetics of soybean and spaghetti[7, 8)], Okazaki and coworkers studied potatoes[9)], and Souma with colleagues worked on fruits and vegetables[10)].

Nonetheless, a prolonged economic recession has resulted in sluggish sake sales, prompting the industry to make an effort to break this trend. A part of this attempt involves attempts to meet diverse consumer preferences, which have compelled breweries to increase sake variety by changing rice polishing ratios. In this study, we suggested a method for mathematical modeling of water absorption curves that can be applied to changes in the rice polishing ratio. In addition, we attempted to use changes in the water absorption curve as parameters for solving the water absorption equation.

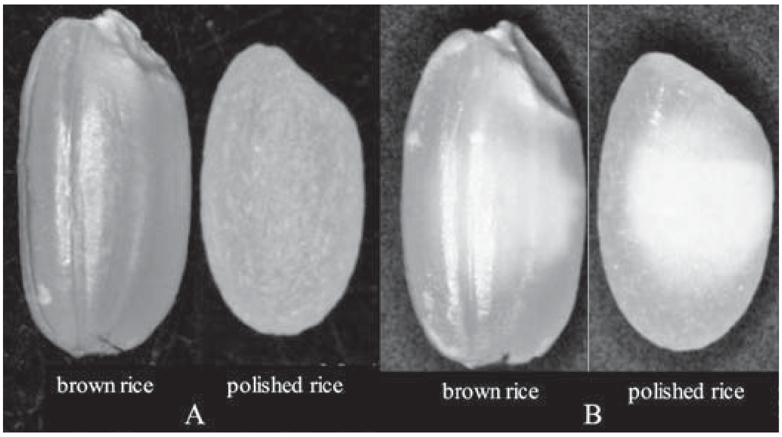
I. Experimental methods

1. Rice

Two strains of rice (*Oryza sativa* L.) produced in 2013 were used: Nipponbare and Gohyakumangoku. Nipponbare is in widespread use as table rice, whereas Gohyakumangoku is a renowned strain of sake brewing rice. The latter type generally has an opaque, white center core in the grain, known as *Shinpaku* structure (Photograph 1). In this study, samples were produced by polishing whole brown rice to 90%, 80%, 70%, 60%, and 50% of the original weight using a pearling mill (the grain-testing mill; Satake Corporation, Higashi-hiroshima, Japan). Water absorption samples were obtained using a desiccator containing silica gel, where samples were placed until their water content reached 11.5%.

2. Measurement of water absorption

Measurements of water content were performed using a modification of the national standard methods for sake brewing[11)]. Ten grams of white rice was put in a stainless



Photograph 1 The exterior view of the Nipponbare and Gohyakumangoku grains.
Panel A shows the table rice, Nipponbare, whereas B shows the brewing rice, Gohyakumangoku. Each strain was photographed as brown rice and polished rice (degree of milling 70%). In Gohyakumangoku, a white opaque *Shinpaku* structure can be observed at the center of the rice grain.

steel mesh container and immersed in a distilled-water tank at 15℃ for 0–60 min. After predetermined periods, samples were taken and immediately centrifuged at 3000 gt (1500 ×*g*, 2 min) to remove the moisture adhering to the surface. The soaking conditions were set to mimic those during sake production. For each sample, the experiment was performed 6 times, and an average value was calculated; the coefficient of variation was <0.2% for the 6 measurements. The data were presented in this paper as averages.

3. Production and modeling of the water absorption curves and solution of the water absorption equation

As in our previous report[5, 6], the water absorption rate x was defined as follows:

$$x = (w - w_0)/(w_e - w_0) \qquad (1)$$

where w (grams) is the sample weight at any given absorption time θ (minutes). The subscripts 0 and e indicate the initial and equilibrium states, respectively; therefore, as w changes from w_0 to w_e, x changes from 0 to 1. The sample weight after momentary soaking served as the initial value, w_0, in order to exclude any influence of the process of removal of water from the rice surface after soaking and also to improve the accuracy of the degree of approximation in the rate equation. For general foodstuffs, approximation of an S-shaped curve to an n^{th} term rate equation yields high accuracy for the processing rate and duration in each process, including water absorbance, drying, heating, and cooling, and is generally considered to be effective[12]. In addition, it was shown in previous studies by the authors assuming the water absorption process of the brewing rice to be an n^{th} term rate equation that affords high accuracy of the fitting, and the included parameters adequately reflect characteristics of the brewing rice[5, 6]. Consequently, parameters were set using the following n^{th} term rate equation as a model equation, and an analysis of changes to the included parameters was performed to test changes in the polished rice ratio.

$$dx/d\theta = k(1-x)^n(x+\alpha) \qquad (2)$$

where x is the water absorption rate and θ is the absorption time (min). The parameter k is expressed in min^{-1}, whereas n and α are parameters derived from experimental data.

4. The method for calculation of parameters

Experimental data related to water absorption were obtained from the relationship between x and θ as per equation (1), whereas parameters for equation (2) were calculated using those data. The established rate equation was solved using numerical integration followed by the nonlinear least-squares method. Solution of the ordinary differential equation was achieved using the Runge-Kutta method.

The following formula shows how the parameters were calculated to minimize the standard deviation,

$$\delta = \left(\sum_{i=1}^{N} (x_{obs} - x_{cal})_i^{\,2} / N\right)^{1/2} \qquad (3)$$

where N is the number of data points, and the subscript *obs* and *cal* are the measured (observed) and calculated values of x, respectively.

II. Results and discussion

1. Water absorption curves for Nipponbare and Gohyakumangoku

The results on water absorption of the table rice Nipponbare and the brewing rice Gohyakumangoku are shown in Figs. 1 and 2. The weight ratio of the samples at each fixed time point θ to the weight of the sample with a soaking time of 0 min (W/W_0) is shown in Fig. 1. The results show that the lower the polishing ratio, the more water is absorbed under all conditions within the testing period.

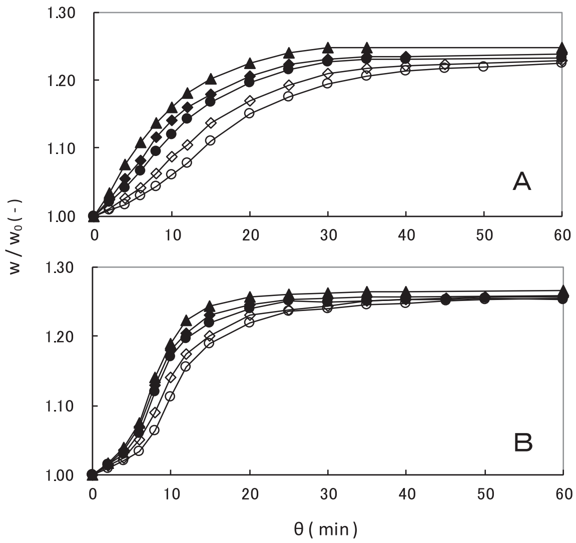


Figure 1 Water absorption curves for Nipponbare and Gohyakumangoku. (1) Changes in the amount of water absorbed (W/W_0) with respect to water absorption time.
Panel A shows table rice, Nipponbare, whereas B shows brewing rice, Gohyakumangoku. Symbols : filled triangles, 50% polished rice (degree of milling 50 %) ; filled diamonds, 60% polished rice ; filled circles, 70% polished rice ; unfilled diamonds, 80% polished rice ; and unfilled circles, 90% polished rice.

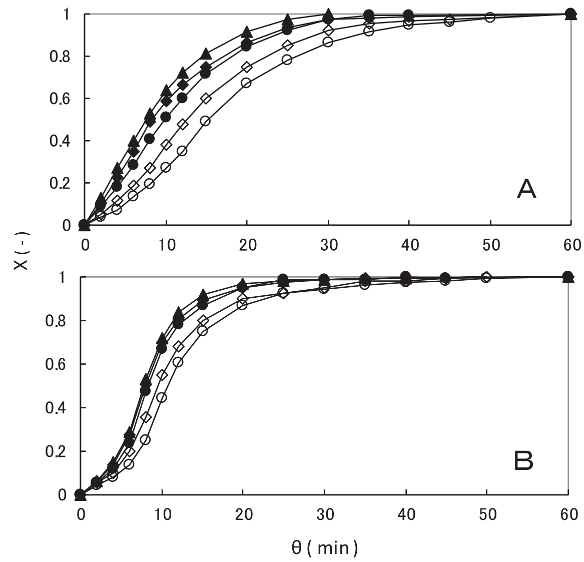


Figure 2 Water absorption curves for Nipponbare and Gohyakumangoku. (2) Changes in water absorption rate (x) with respect to water absorption time. The description of panels A and B and symbols is the same as in Figure 1.

The possible reason is that starch plays the main role in the mechanism via which rice absorbs water. In other words, because the starch content rises as the rice polishing ratio decreases (because the inside of the rice grain contains the greatest level of starch), the amount of water absorbed also increases.

The water absorption rate, x, for each soaking period is shown normalized to 1.0 in Fig. 2. In the case of Nipponbare, rice polished at 70% (the degree of milling 70%) that is used in normal sake brewing leads to a considerably less steep S-shaped curve of water absorption, confirming the results of previous studies[5]. In contrast, a steeper curve was observed for the rice with a high polishing ratio (80% and 90%), with an inflection point at 8–15 min. Many components are distributed throughout the outer layer of rice, including proteins, which absorb water worse than starch does, and lipids, which inhibit the absorption of water by starch[13]. Therefore, it is likely that water absorption in this region is restricted. The discussion that follows will focus on the brewing rice Gohyakumangoku, which has *Shinpaku* structure. For Gohyakumangoku, the S-shape weakened as the rice polishing ratio decreased, but was clearer for all rice polishing ratios. This trend was stronger in Gohyakumangoku than in Nipponbare. The *Shinpaku* structure of the brewing rice is shown in Photograph 1 as a white, opaque structure inside the rice grain. This white, opaque part has been shown to have low density of starch and large amounts of empty space; its features have been observed by Ando *et al.* under a scanning electron microscope[14]. It seems that the rate of water absorption increases when water permeating from the outer layer reaches the *Shinpaku* structure. This is because the water absorption phenomenon progresses while filling the empty space. The water absorption characteristics of these *Shinpaku* structures also seem to account for the greater curvature in the S-shaped absorption curve of Gohyakumangoku, as does the wide distribution of components that inhibit water absorption throughout the outer layer.

2. Solution of the water absorption equation (modeling of the water absorption curves) and extraction of parameters

The values of the parameters of the water absorption equation (equation 2) were calculated using the least-squares method (equation 3) and are shown in Fig. 3. One of the aims of the present study was to develop a model of the water absorption curve for rice that was simple and could be reproducibly applied to the actual practice of brewing. In addition, because the error in the fitting is not large, n was assumed to be 1.0 in calculations because of the need for convenience in the implementation of this method, according to a previous study[6]. In other words, Fig. 3 was obtained using values of k and α in $dx/d\theta = k(1-x)(x+\alpha)$ so as to minimize δ in equation 3. The parameter k shows the rate of water absorption, with low values of α affording S-shaped curves with greater curvature. For Nipponbare, α increased as the rice polishing ratio decreased, meaning that the curvature of the S-shaped curve decreases

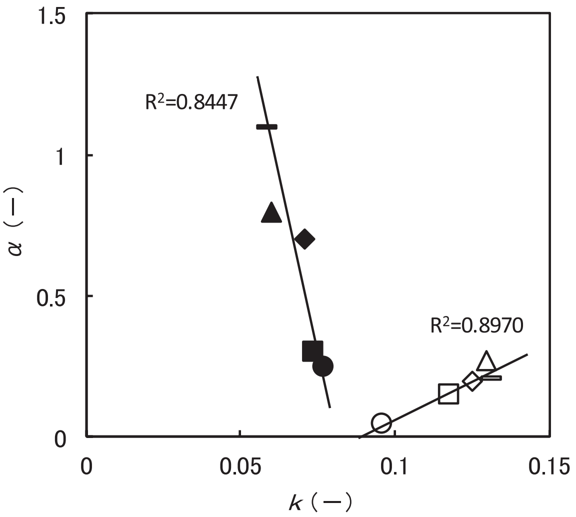


Figure 3 Distribution of parameters of the water absorption equation.
Symbols : filled shapes, the table rice Nipponbare ; unfilled shapes, the brewing rice Gohyakumangoku ; circles, 90% polished rice (degree of milling 90%) ; squares, 80% polished rice ; diamonds, 70% polished rice ; triangles, 60% polished rice ; and bars, 50% polished rice.
The parameter α contributes to the curvature of the S-shape of the water absorption curve, with higher values yielding a reduced curvature ; k contributes to the rate of water absorption, with higher values indicating a faster rate. R^2 : coefficient of determination.

with polishing. This situation likely results from a reduction in the components inhibitory to water absorption widely distributed throughout the surface layer. On the other hand, the higher the polishing ratio, the more the parameter k value increased by a slight amount. Equation 2 used in this examination was capable of expressing in a low parameter number, the curvature of the S-shape curves. However, it was indicated that when the curve whose curvature changed greatly, the separation of parameter α and k had the possibility of becoming unclear[5]. Therefore, the test inferred that the reason why the k value of a highly polished rice, increased somewhat was that the two parameters were unable to separate clearly in mathematical terms. For Gohyakumangoku, any rice polishing ratio has a smaller α value compared to Nipponbare, as reflected in the characteristics of the water absorption curve, which exhibits greater curvature. There was a small difference between high and low polishing ratios of Gohyakumangoku. This is probably because the *Shinpaku* structure increased the rate of water absorption, while the rice with a low polishing ratio was not influenced by the properties of the outer layer.

In this work, we analyzed the effects of the rice polishing ratio on water absorption using absorption curves and parameters of the absorption equation. Therefore, it is now possible to better understand the specific changes introduced by the *Shinpaku* structure of the brewing rice. Furthermore, the present method has been shown to be capable of tracking the changes in the rice polishing ratio, and we used the Nipponbare and Gohyakumangoku strains of rice to confirm its utility. In the future, it will be necessary to evaluate these trends in other strains of rice. Although we attempted to calculate the inflection points of the S-shaped curves, we were unable to do so because of the large influence exerted by small differences in the analyzed values. In the future, it will be necessary to incorporate additional factors into the water absorption equation, such as soaking conditions and distribution of components inside the rice grain.

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