

## Kinetic Studies on Cooking of Rice of Various Polishing Degrees

Hong-Sik Cheigh, Sung-Kon Kim, Yu-Ryang Pyun\* and Tai-Wan Kwon

Food Technology Lab., Korea Institute of Science and Technology, Seoul

\*Dept. of Food Engineering, Yonsei University, Seoul

(Received November 19, 1977)

### 도정도별 쌀의 취반에 대한 역학적 연구

최홍식 · 김성곤 · 변유람\* · 권태완

한국과학기술연구소 식품공학연구소, \*연세대학교 식품공학과

(1977년 11월 19일 수리)

#### Abstract

The mechanism of cooking rice was investigated using a japonica type rice variety, Akibare, of 50%, 70% and 90% polishing degrees. The hardness of rice cooked at various cooking temperatures (90°-120°C) was measured with a Texturometer. The cooking rate followed the equation of a first-order reaction. The reaction rate constants were in the increasing order of 50%, 70% and 90% polished rice. The temperature coefficient of the reaction rate constant at cooking temperatures of 90°-100°C was about 2 in all rice samples. The activation energies of cooking at temperatures below 100°C and above 100°C were about 17,000 and 9,000 cal/mole, respectively. The polishing degrees and water soaking time of rice did not affect the activation energy of cooking; however, the lower polishing degrees and shorter soaking increased the cooking time. The experimental results suggested that the cooking process of rice comprises two mechanisms: At temperatures below 100°C the cooking rate is controlled by the reaction rate of rice constituents with water, and at temperatures above 100°C, it is controlled by the rate of diffusion of water through the cooked portion (or layer) toward the interface of uncooked core in which the reaction is occurring.

#### Introduction

It is reasonable to consider that the cooking process of rice comprises the gradual absorption of water from the surface to the inner portion of the rice grain and the physicochemical changes or reactions, of rice constituents with water by heating. Since the cooking occurs from the outside to the center of the rice grains and the cooked parts become soft, the ratio of the soft part to the original volume may be conver-

tible into the degree of the cooking.<sup>(1)</sup>

By employing a parallel plate plastomer technique for measuring the degree of cooking, Suzuki *et al.*<sup>(1)</sup> investigated the rate of cooking of rice. Their results suggested that two different mechanisms operate during the cooking process of rice; at temperatures below 110°C, the cooking rate is limited by the reaction rate of rice constituents with water; and at temperatures above 110°C, it is limited by the rate of diffusion of water through the cooked layer toward the interface of uncooked core where the reaction occurs.

The purpose of this study was to investigate the kinetics of cooking process of rice of various polishing degrees with a Texturometer and to examine the mechanism(s) of the cooking process of rice at various cooking temperatures.

### Materials and Methods

#### Materials

A japonica rice variety, Akibare, was used throughout the experiment. It was polished at 50, 70 and 90% using an abrasive mill, sealed in a polyethylene film bag and stored in a refrigerator until used.

The proximate composition of rice samples is given in Table 1.

#### Cooking of rice

The apparatus used for cooking of rice was a 12mm (inner diameter)×28mm brass vessel which is able to endure an inner pressure at 140°C by sealing a packing and a screw cap.

One gram of rice and 1.4ml water were taken into the vessel and soaked for 30min. The rice was then cooked in an oil bath for a fixed time at a range of temperatures (90°–120°C) and cooled for 1 min in an ice water.

The hardness of the cooked rice grain was measured using a Texturometer (General Foods Co., U.S. A.). The conditions for the Texturometer were: plunger, 18mm lucite; voltage, 1.5V; attenuator, 1.0; clearance, 0.25mm; bite speed, high (24 cycle/min); chart speed, 750mm/min; and sample height (average), 2.0mm.

### Results and Discussion

The relation between the reciprocal hardness of cooked rice grains and cooking time at each cooking temperature of 50%, 70% and 90% polished rice is

Table 1. Proximate composition of rice

	Moisture (%)	Protein (%)	Lipid (%)	Cellulose (%)	Fiber (%)
50% polished rice	10.8	7.44	1.68	1.52	0.96
70% Polished rice	10.9	7.35	1.62	0.98	0.91
90% Polished rice	10.9	7.12	1.52	0.67	0.76

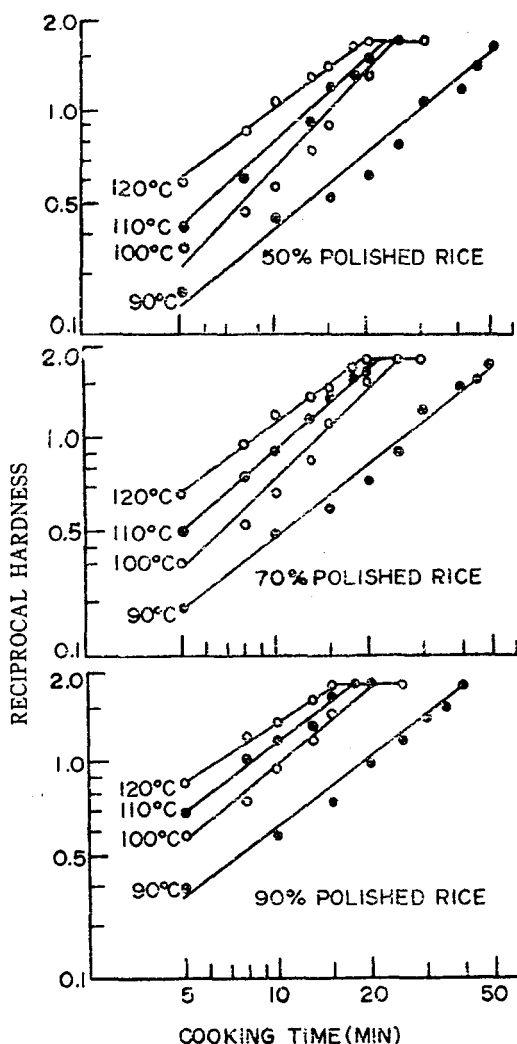


Fig. 1. Relation between the reciprocal hardness of cooked rice grains and cooking time at various cooking temperatures (Soaking time, 30 min).

shown in Fig 1. Each curve showed a clear linear relationship. The reciprocal hardness at each cooking temperature reached a constant value after certain cooking time, at which a bending of the curve occurred. The hardness value of the cooked rice grains at the bending point, which was defined as the terminal point of cooking at each cooking temperature, was 0.57 (or 1.57 as reciprocal hardness value) in all rice samples (Fig. 1).

The relation between the cooking time to the terminal point of cooking and the cooking temperature

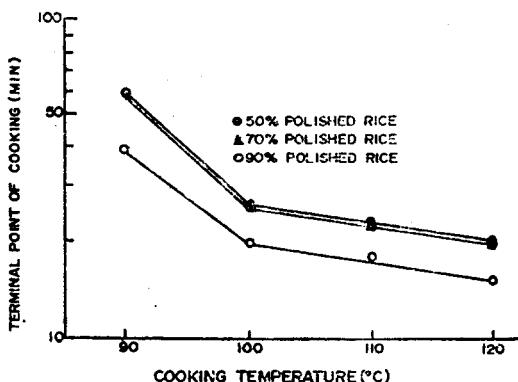


Fig. 2. Relation between the terminal point of cooking and cooking temperature (Soaking time, 30 min).

is shown in Fig. 2. The cooking time to the terminal point of cooking was in the decreasing order of 90%, 70% and 50% polished rice. This order was not affected by the cooking temperature. However, the cooking time to the terminal point of cooking had an inverse relationship with the cooking temperature.

The cooking time showed a linear function of the cooking temperature, but the slopes of the curves changed at 100°C (Fig. 2). At cooking temperatures of 90°-100°C, the slope for the 90% polished rice was somewhat less steeper than the slopes for the 50% and 70% polished rice which showed about the same trend. However, at a temperature above 100°C, the slopes were nearly constant for all cases. These results indicate that the cooking rate of rice slows down at elevated temperatures (*i.e.*, above 100°C).

If it is accepted from the results in Fig. 1 that the reciprocal hardness is proportional to the degree of cooking ( $\alpha$ , having a negative value), the kinetics of the cooking of rice can be analyzed from Fig. 1.  $\alpha$  can be expressed as follow:

$$\alpha = \frac{H_t - H_o}{H_L - H_o}$$

where  $H_o$  and  $H_t$  are hardness at cooking time 0 and  $t$ , respectively and  $H_L$  is the hardness at terminal point of cooking. As indicated earlier, the value for the terminal point of cooking was 0.57. The measured values of  $H_o$  were 3.60, 3.56 and 3.50 for 50%, 70% and 90% polished rice, respectively. These values indicate that the water absorption of the uncooked

rice grains which were soaked for 30 min is in the decreasing order of 90%, 70% and 50% polished rice.

A plot of the rate of uncooked portion of rice, expressed as  $1-\alpha$ , as a function of cooking time is shown in Fig. 3. As evident from this figure, the rate of uncooked portion of rice showed a linear relationship with the cooking time. The results in Fig. 3 thus can be expressed as a first-order reaction:

$$\ln(1-\alpha) = -kt$$

where  $k$  is termed the reaction rate constant and  $t$  is the cooking time.

The reaction rate constants calculated from Fig. 3 are presented in Table 2. The reaction rate constants were increased as the cooking temperatures increased and were in the increasing order of 50%, 70% and 90% polished rice. The temperature coefficient of the reaction rate constants between 90° and 100°C was about 2 (Table 2), which is nearer to the value by chemical reaction than biochemical reaction.<sup>(1)</sup>

The relation between the cooking rate constant and the reciprocal cooking temperature is shown in Fig. 4.

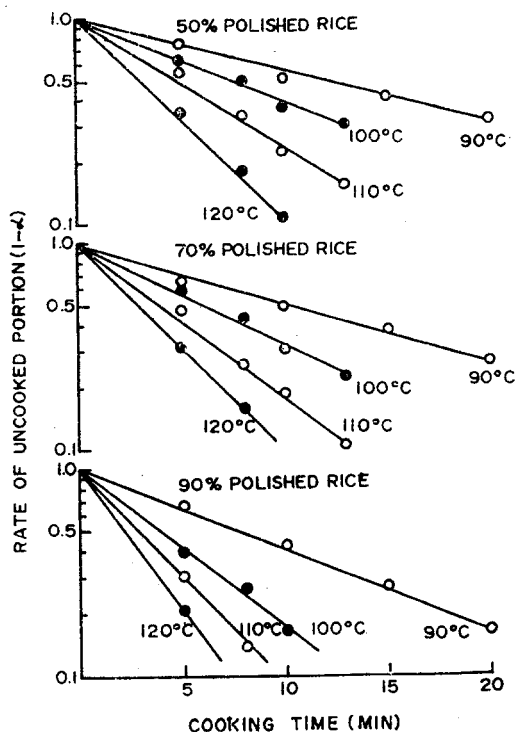


Fig. 3. The rate of uncooked portion of rice grains as a function of cooking temperature (Soaking time, 30 min).

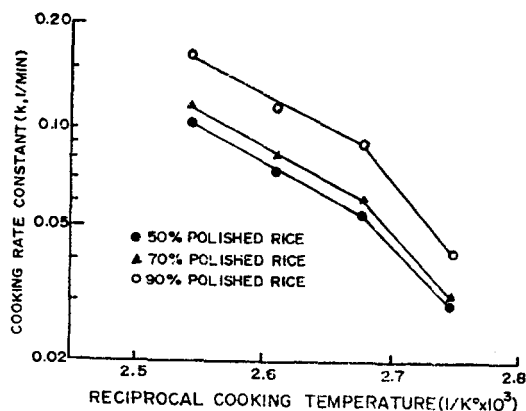
**Table 2. Average values of the reaction rate constant (Soaking time, 30 min)**

Cooking temperature	Reaction rate constant		
	50% polished rice	70% polished rice	90% polished rice
90°C	$2.9 \times 10^{-2}$	$3.1 \times 10^{-2}$	$4.2 \times 10^{-2}$
100°C	$5.4 \times 10^{-2}$	$5.9 \times 10^{-2}$	$8.3 \times 10^{-2}$
110°C	$7.0 \times 10^{-2}$	$8.0 \times 10^{-2}$	$10.7 \times 10^{-2}$
120°C	$10.1 \times 10^{-2}$	$10.6 \times 10^{-2}$	$15.8 \times 10^{-2}$

The slope changed at 100°C, which indicates that the activation energy of the cooking rice changes at 100°C. These results imply that the cooking process (or mechanism) of rice below and above 100°C may be different.

The activation energies calculated from Fig. 4 are given in Table 3. The activation energies between 90°-100°C and 100°-120°C were about 17,000 and 9,000 cal/mole, respectively. The polishing degrees of rice and soaking time did not affect the activation energy. The results in Table 3 are in good agreement with those of Suzuki *et al.*<sup>(1)</sup> who reported 19,000 cal/mole at 75°-100°C and 8,800 cal/mole at 110°-150°C for 100% polished rice.

The process of the cooking rice is considered to consist of the gradual absorption of water from the surface to the inner portion of the rice grain and the physicochemical reactions of rice constituents with water by heating. On the assumption that the cooking rate is limited only by the reaction of rice constituents with water and is considered independently



**Fig. 4.** Relation between the cooking rate constant and the reciprocal cooking temperature (Soaking time, 30 min).

from the rate of diffusion of water, Suzuki *et al.*<sup>(1)</sup> calculated the reaction rate constants and reported that the temperature coefficient of the reaction rate constant is about 2, which is in good agreement with results in Table 2. Since the temperature coefficient value of 2 for the reaction rate constant is nearer to the value by chemical reaction than biochemical reaction, it seems that the cooking rate may be controlled by the reaction rate of the rice constituents with water at cooking temperatures of 100°C and below.

It is known<sup>(2)</sup> that the heterogeneous catalytic reactions, in general, involve the diffusion of reactants; the activation energy observed in the diffusion-limited reaction is about one-half of the activation energy in the case of reaction only, since the activation energy of diffusion seems negligibly small compared with that of the reaction. It is reasonable to consider that the cooking rice is a heterogeneous catalytic reaction involving diffusion of water and physicochemical reactions. The fact that the activation energy between 100°-120°C was about one-half compared with that between 90°-100°C (Table 3) thus suggests that, at cooking temperatures above 100°C, the cooking rate may be controlled by the rate of diffusion of water.

As indicated previously, the activation energies of cooking rice were not affected by the polishing degrees and water soaking time of rice. However, the lower polishing degrees (Fig. 2) and shorter soaking increased the cooking time of rice. Since the presence of water, or the quantity of the soaked water in the grain depends on the change of cooking rate,<sup>(1)</sup> the higher contents of rice constituents other than starch in 50% and 70% polished rice than 90% polished rice (Table 1) may act as a barrier for the diffusion of water, which is needed for the cooking from the sur-

**Table 3. Activation energies of cooking rice (Soaking time, 30 min)**

	Cooking temperature	
	90°-100°C	100°-120°C
50% polished rice	16,800 cal/mole	9,100 cal/mole
70% polished rice	17,400	8,600
90% polished rice	17,400	9,000
90% polished rice*	17,100	8,900

\* Soaking time, 10 min.

face to the core of the rice grains; thus resulting in slowing down the chemical reaction which in turn delays the cooking of rice.

### 요 약

쌀의 취반에 대한 기작을 아끼바레(도정도, 50%, 70% 및 90%)를 이용하여 연구하였다. 취반(취반온도 90°-120°C)후 밥알의 hardness는 Texturometer로 측정하였다. 취반속도는 1차 반응의 식으로 표시될 수 있었으며, 취반온도 90°-100°C사이의 온도 계수는 2 이었다. 취반의 활성화 에너지는 100°C이하에서는 약 17,000cal/mole, 100°C이상에서는 약 9,000cal/mole이었다. 쌀의 도정도 및 쌀의 취반전 침지시간은 활성화 에너지에 영향을 주지 않았으나, 반응속도 상수는 도정도가 높

아질수록 증가하였고 취반시간은 반대로 감소하였다. 쌀의 취반과정은 다음의 두 기작으로 설명할 수 있었다. 즉 취반온도 100°C이하에서는 쌀의 성분 및 물에 의한 화학반응이, 취반온도 100°C이상에서는 취반된 부분으로부터 취반되지 않은 부분(즉 반응이 진행되고 있는 부분)으로의 물의 확산속도가 취반속도를 제한하였다.

### References

- 1) Suzuki, K., Kubota, K., Omichi, M., and Hosaka, H.: *J. Food Sci.*, 41, 1180(1976).
- 2) Satterfield, C.N.: *Mass Transfer in Heterogeneous Catalysis*, p. 129 and 208, M.I.T. Press (1970).