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Kinetic Studies on Cooking of Tropical Milled Rice

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ABSTRACT

Four aged tropical milled rices differing in amylose content and/or starch gelatinization temperature (GT) were presoaked for 30 min and cooked in calculated weights of water based on amylose content at 80, 90, 100, 110 and 120°C. Differences in cooking rates were evident below 100°C. Activation energy of cooking, derived from Arrhenius plots of cooking rate constant and reciprocal temperature, ranged from 76 to 121 kJ/mole at 80–90°C and 31–57 kJ/mole at 90–120°C. Cooking rates were lower and activation energy values were higher for intermediate GT samples than for low GT samples.

INTRODUCTION

Kinetic studies on cooking of milled rice have been confined to japonica rices with low amylose content and low gelatinization temperature (GT) (Suzuki *et al.*, 1976, 1977; Cheigh *et al.*, 1978; Cho *et al.*, 1980). The activation energy of cooking at temperatures below 100°C is higher than that above 100°C. Below 100°C, the cooking rate is limited by the reaction rate of rice components with water, but, above 100°C, it is determined by the rate of diffusion of water through the cooked layer toward the interface of uncooked core where the reaction occurs (Suzuki *et al.*, 1976, 1977). The activation energy of cooking is not affected by

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degree of milling and presoaking time which, however, prolongs cooking time (Cheigh *et al.*, 1978). Some differences in activation energy of cooking were observed between a japonica rice and an indica-japonica rice (Cho *et al.*, 1980). Hardness of the cooked rice has been measured with a parallel plate plastometer (Suzuki *et al.*, 1976) or a Texturometer with Lucite plunger (Cheigh *et al.*, 1978; Cho *et al.*, 1980).

Bandyopadyay & Roy (1978) reported that the activation energy of hydration of Indian rough rice above the starch GT (60–69 °C) was much higher than below GT. The higher temperature (70–80 °C) activation energies of 97 000–133 000 kJ/mole were higher than the value of 72 000–84 000 kJ/mole reported for cooking of milled rice at 80–100 °C (Suzuki *et al.*, 1976, 1977; Cheigh *et al.*, 1978; Cho *et al.*, 1980).

Russell & Juliano (1983) reported similar energy (1·405–1·563 kJ/g dry starch) required to cook, from 20 °C to 100 °C, eight rice starches differing in amylose content and GT at a water:starch ratio of 4. Gelatinization enthalpy ranged from 11·3 to 17·3 J/g dry starch for the same eight starches while the enthalpy of amylose–lipid complex melting was even less ($<$ 3 J/g).

The study was undertaken to determine the applicability of published kinetic data on japonica rice to tropical rice and the relevance of the soaking data on tropical rough rice at 70–80 °C to the cooking properties of milled rice below 100 °C.

MATERIALS

Aged samples of IR29, IR28150-84-3-3-2, IR32 and IR42 were obtained from the IRRI farm, dehulled in a Satake THU 35 dehuller and milled in a Satake TM-05 grain testing mill. Head rice was sized with a Satake TRG-05A testing rice grader.

METHODS

Samples were analyzed in duplicate for crude protein by the micro-Kjeldahl method using the conversion factor 5·95 (Juliano & Pascual, 1980); amylose by iodine colorimetry (Juliano *et al.*, 1981); alkali spreading value (Little *et al.*, 1958); gel consistency (Cagampang *et al.*, 1973); mean length, thickness and width of 10 grains and 100-grain weight

TABLE 1
Physico-chemical Properties of Milled Rice Samples

Property	*IR29*	*IR28150-84-3*	*IR32*	*IR42*
100-grain weight (g)	1·56	1·74	1·67	1·49
Milled rice length (mm)	6·3	6·6	6·5	5·7
Milled rice width (mm)	2·1	2·1	2·0	2·2
Milled rice thickness (mm)	1·6	1·7	1·5	1·6
Amylose content (per cent dry basis)	1·5	22·6	27·8	28·2
Alkali spreading value	7·0	3·5	5·0	7·0
Final GT (°C)	66	74	72	62
Gel consistency (mm)	100	74	92	28
Crude protein (per cent dry basis)	8·8	9·3	8·6	10·8

and photometric GT (Ignacio & Juliano, 1968). Samples were so selected to have differences in amylose content and/or starch GT (Table 1).

Milled rice (1 g) was placed in 5 ml prescored Wheaton glass ampoules with 1·1 g water for IR29, 1·9 g water for IR28150-48-3 and 2·1 g water for IR32 and IR42 based on amylose content (Juliano & Pascual, 1980). The ampoules were sealed. After soaking at room temperature for 30 min, the ampoules were transferred into silicone oil in a Haake Model A80 constant temperature bath for given periods at 80, 90, 100, 110 and 120 °C. The grains were then cooled to room temperature for 1 h, the ampoule neck was broken and three cooked grains were used for hardness estimation with an Instron Model 1140 Food Tester with the 18 mm diameter Lucite plunger of the Texturometer (Juliano *et al.*, 1984). Crosshead speed was 10 mm/min, chart speed was 100 mm/min and compression was adjusted to about 70 % (0·45 mm clearance) using the 50 kg load cell. The height of the first compression peak, in kilograms, was considered the hardness value and the mean of at least five readings was reported.

Hardness of raw, soaked milled rice (H_0) was determined by extrapolation of plot of ln reciprocal hardness against cooking time. Mean hardness at terminal point of cooking (H_L) and cooking time to terminal point of cooking were estimated from a plot of ln reciprocal hardness against ln cooking time (Suzuki *et al.*, 1976; Cheigh *et al.*, 1978). A plot was then made of ln $(1 - \alpha)$ as a function of cooking time where $\alpha = H_t - H_0/H_L - H_0$ where H_t = hardness at time t. The reaction rate constant was calculated from the slope of the plot of ln $(1 - \alpha)$ versus t and a plot made of ln k as a function of reciprocal cooking temperature in degrees Kelvin. The activation energy was calculated from the slope from the Arrhenius equation:

$$\ln k = E_{\alpha}/RT + \text{constant}$$
$$E_{\alpha} = \ln k/(1/T) \times R$$

where $R = 8{\cdot}3144$ J/K-mole.

RESULTS AND DISCUSSION

Because it was difficult to directly obtain grain hardness of raw presoaked sample, the value was obtained by extrapolation of $\log(1/H)$ as a function of cooking time. Values obtained were 40·0 kg for IR29, 47·6 kg for IR28150-84-3, 50·0 kg for IR32 and 33·3 kg for IR42. The plot of $\ln(I/H)$ against ln cooking time showed a series of almost parallel lines with increasing cooking temperature except for IR28150-84-3 (Fig. 1). The 80 °C line for IR28150-84-3 had lower slope than the higher temperature lines. Terminal cooked rice hardness was 1·98 kg for IR29, 2·86 kg for

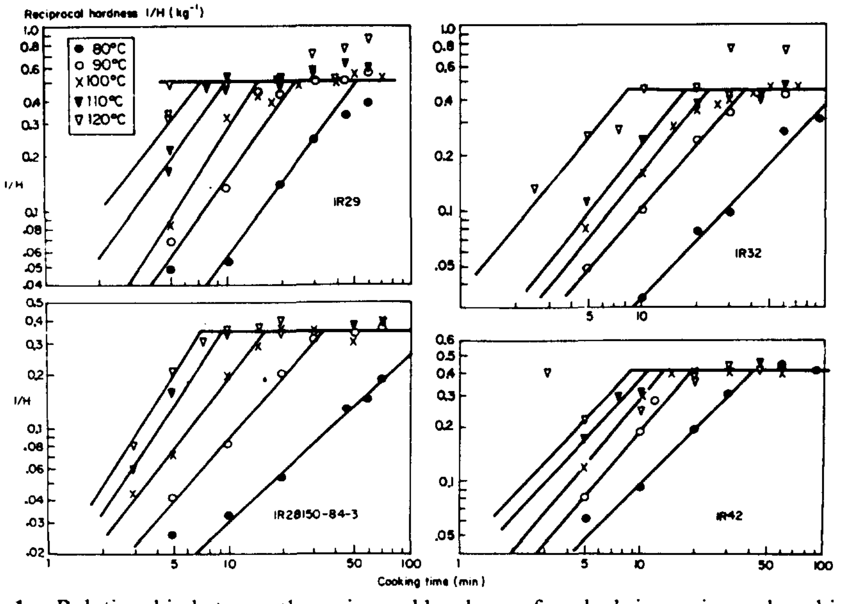

Fig. 1. Relationship between the reciprocal hardness of cooked rice grains and cooking time at various cooking temperatures. Soaking time was 30 min in calculated optimum weight of water.

IR28150-84-3, 2·22 kg for IR32 and 2·44 kg for IR42, corresponding to reciprocal hardness of 0·505 kg^{-1} for IR29, 0·35 for IR28150-84-3, 0·45 for IR32 and 0·41 for IR42. The widely scattered $1/H_t$ values for IR29 at longer cooking times and higher temperatures was due to the difficulty of getting discrete grain samples for hardness testing because of disintegration of cooked grains. The higher terminal hardness for IR28150-84-3 was probably due to its thicker grain.

Cooking time to terminal point of cooking decreased with increasing cooking temperature for all four samples and differences were greatest at 80 °C (Table 2). At 80 °C and 90 °C, the two samples with low GT, IR29 and IR42, had shorter cooking times than the intermediate GT IR28150-84-3 and IR32. Overlapping values were obtained for the two GT types at 100, 110 and 120 °C but IR32 had a longer cooking time at 100 °C and 110 °C. Reported cooking times for japonica rices are 8–38 min at 120–80 °C (Suzuki *et al.*, 1976), 15–40 min at 120–90 °C (Cheigh *et al.*, 1978) and 13–34 min at 120–90 °C (Cho *et al.*, 1980).

The rate of uncooked portion ln $(1 - \alpha)$ showed a linear relationship with the cooking time; the slope decreased with increase in cooking temperature (Fig. 2). The differences in slope were greatest between 80° and 90° for all four samples. The corresponding rate constants obtained

TABLE 2

Summary of Cooking Properties of Tropical Milled Rices Cooked at Various Temperatures after 30 Min Soaking

Property	*IR29*	*IR28150-84-3*	*IR32*	*IR42*	*Mean*
Water:rice ratio	1·1	1·9	2·1	2·1	1·8
Cooking time (min) at					
80 °C	52	134	116	41	86
90 °C	24	34	36	19	28
100 °C	15	16	23	13	17
110 °C	10	9	17	11	12
120 °C	7	7	8	9	8
Rate constant k (10^2 min^{-1}) at					
80 °C	9·54	4·95	5·90	12·5	8·25
90 °C	21·9	15·8	15·7	26·0	19·8
100 °C	28·8	29·2	23·9	34·6	29·1
110 °C	48·7	47·5	32·4	42·2	42·7
120 °C	70·3	65·3	59·0	55·5	62·5

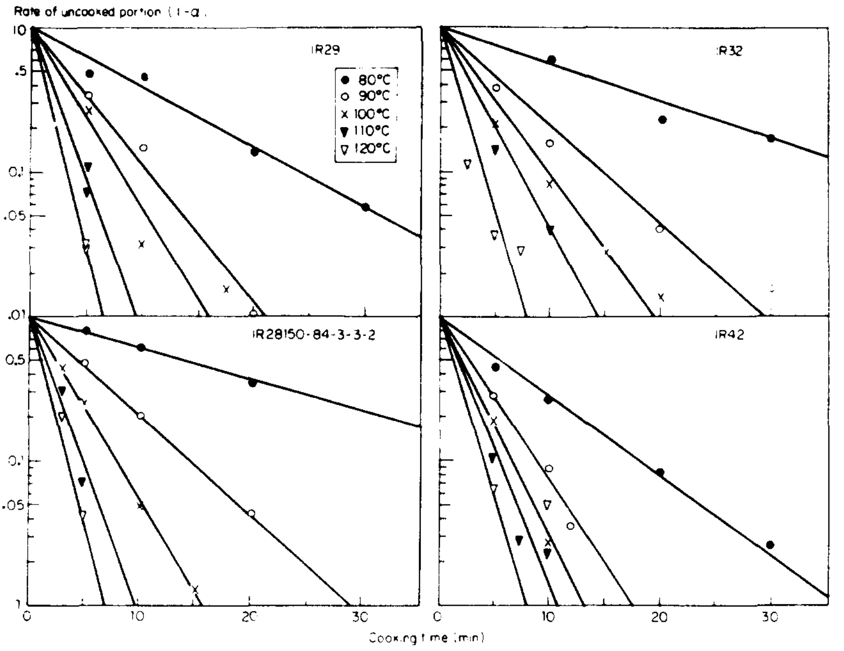

Fig. 2. The rate of uncooked portion of rice grains as a function of cooking temperature. Grains were presoaked for 30 min in calculated optimum weight of water.

from Fig. 2 also increased with increasing cooking temperature (Table 2). Only between 80 °C and 90 °C was the temperature coefficient of the reaction rate constant about 2/10 °C (2·4) (Table 2) in contrast with the temperature coefficient of 2/10 °C for the entire temperature range of 75–100 °C for japonica rice (Suzuki *et al.*, 1976; Cheigh *et al.*, 1978; Cho *et al.*, 1980). Mean temperature coefficients were 1·5/10 °C between 90 °C and 100 °C, 100 °C and 110 °C and 110 °C and 120 °C.

The plot of ln k and reciprocal cooking temperature showed a higher slope at 80 °C to 90 °C than at 90–120 °C (Fig. 3), suggesting that the change in reaction mechanism of cooking occurs at about 90 °C instead of 100–110 °C. Calculated activation energies of cooking were higher for intermediate GT samples than low GT rices, particularly at 80–90 °C (Table 3). The slope was similar at 90–120 °C except in IR28150-84-3 which showed an intermediate slope at 90–100 °C (Fig. 3). Correspondingly, activation energies for cooking were higher at 80–90 °C (about double) than at 90–120 °C (Table 3).

The energy values obtained (Table 3) were similar to those reported for japonica rices (Suzuki *et al.*, 1976, 1977; Cheigh *et al.*, 1978; Cho *et al.*,

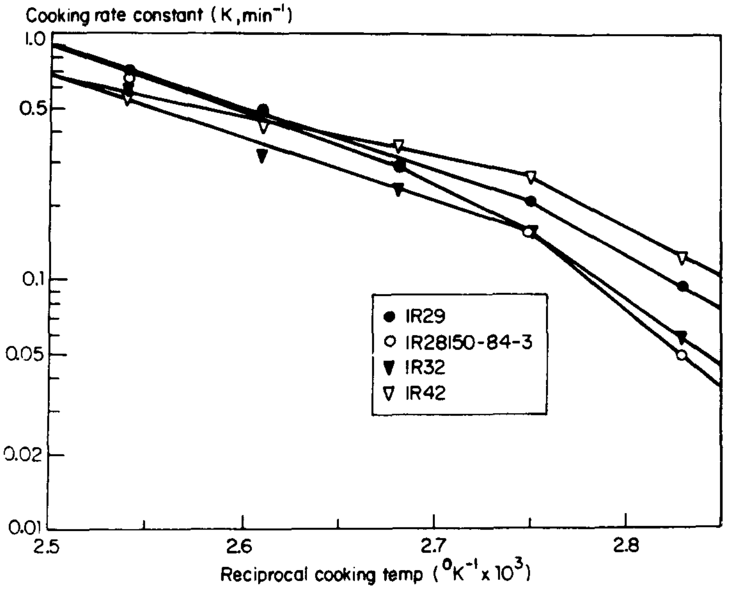

Fig. 3. Arrhenius plots of the cooking rate constants of milled rice. Grains were presoaked for 30 min in calculated optimum weight of water.

1980) (Table 4) only with IR42. IR29 values are probably overestimated because of the ease of disintegration of overcooked grains, characteristic of waxy rice (Juliano, 1979), which makes sampling of cooked grains very difficult. The two intermediate GT samples had higher activation energy values, particularly at 80–90 °C, than those reported (Tables 3 and 4). IR28150-84-3 had the highest activation energy of the four samples. The lowest cooking temperature of 80 °C is only 6–8 °C above the GT of

TABLE 3
Calculated Activation Energy of Cooking Milled Rice after 30 Minutes' Soaking

Sample Name	*Amylose content* (%)	*Final gelatinization temperature* (°C)	*Activation energy* (*kJ/mole*)	
			80–90 °C	*90–120 °C*
IR29	1·5	66	88	46
IR28150-84-3	22·6	74	121	57[a]
IR32	27·8	72	102	49
IR42	28·2	62	76	32
Mean			97	46

[a] Weighted mean of 68 kJ/mole at 90–100 °C and 52 kJ/mole at 100–120 °C.

TABLE 4
Comparison of Activation Energy of Cooking Rice

Source	*Form of rice*	*Water:rice ratio*[a]	*Activation energy (kJ/mole)*	
			80–100°C	*100–120°C*
Suzuki *et al.* (1976)	Milled	1·4	79·5	37
Suzuki *et al.* (1977)	Milled	1·4	84	—
Cheigh *et al.* (1978)	Milled	1·4	73	38
Cho *et al.* (1980)	Milled	1·4	72, 78	40, 36
Bandyopadhyay & Roy (1978)	Rough	0·7	97, 105[b]	—
This paper (Table 3)	Milled	1·1–2·1	76–121[c]	32–57[c]

[a] Water:rice (wet basis) ratio. Moisture content was 12% wet basis.
[b] 70–80°C only.
[c] 80–90°C and 90–120°C, respectively.

IR28150-84-3 and IR32, but 14–18°C above the GT of IR29 and IR42. Higher activation energy was obtained by Bandyopadyay & Roy (1978) for hydration of low GT rough rice above the starch GT at 70–80°C (Table 4). The values reported overlapped with that of IR32 but were still lower than that for IR28150-84-3 at 80–90°C. However, earlier reported values for activation energy for hydration of rough rice above the GT of starch cited by these authors were higher at 106–133 kJ/mole, which coincides with the value for IR28150-84-3. Activation energy for hydration also tended to be higher for the higher GT (67–69°C versus 60–63°C) rough rices (Bandyopadyay & Roy, 1978).

IR42 has hard gel consistency and high amylose and high volume expansion on cooking and had less soluble starch during cooking than IR32 and intermediate amylose rices (Juliano, 1979). These properties probably facilitate faster water diffusion into the cooking grain in addition to its low GT. This combination of properties, plus the lighter grain, probably contribute to the lower activation energy for IR42, relative to the three other samples. IR32 had the highest soluble starch of the set (Juliano, 1979).

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