# Thermal Processing Effects on Rice Characteristics

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## Abstract

Whole kernels of four cultivars of milled rice were treated under different conditions according to our traditional methods such as boiling, steaming, autoclaving or roasting with sand. During the various processing conditions, the moisture contents of the kernel, heating temperatures, pressures and heating times were varied. In this paper, the physicochemical properties of those processed samples were investigated and compared.

Based on degree of gelatinization, water absorption index, water solubility index, swelling power, viscoamylograms and X-ray diffraction patterns, the properties of waxy rice samples are different from that of non-waxy rice samples. They are also different even among the non-waxy rice samples. Besides, each processed sample under diverse treatments has its own properties. In boiled samples, the starch granules almost gelatinized to form a film-like gel substance, whereas in other processed samples, ungelatinized starch granules were noticeable.

## Introduction

Rice is the staple crop in Taiwan and in southeast Asia. A wide variety of foods are produced by different processes. The processing conditions, as regards the water content, pressure, temperature and shear forces, are different. Starch, the major component of rice, may be modified to different extents. This could have important effects on both the physicochemical and functional properties of the products.

Heating of cereals under various conditions has been reported by many workers [13, 15, 27, 36]. Extensive literature is available on the processing conditions and the physicochemical properties of paddy and parboiled rice [9-11, 24, 28, 30], while information on processed milled rice products is scanty [6, 8, 17, 23, 34]. Boiling and steaming methods are usually used at home for preparing rice foods. Powders of rice, roasted with sand, are used in factories for making some special cakes. This study compares boiling, steaming, autoclaving, and roasting of whole rice kernel with different amylose contents in regard to some physicochemical properties as well as their *in vitro* $\alpha$-amylase digestibility of the starch component.

## Materials and Methods

### Materials

Milled rice from four cultivars (Kaohsiung Sen 7, KSS7; Taichung Sen 10, TCS10; Tainung 67, TNu67; and Taichung waxy 46, TCW46) was used in the experiment. Two of them (KSS7 and TCS10) were sen rice (indica type), one (TNu67) was geng rice (japonica type) and the other (TCW46) was waxy rice. They were dehulled and polished using a domestic rice huller and polisher (the yield of milled rice was about 70%), and supplied by the Taichung District Agricultural Improvement Station, as the second crop of 1988. The processed samples were prepared after storage for at least 6 months at 12-15°C.

To obtain boiled samples, the rices were washed and put into distilled water [rice:water (weight/weight, w/w) ratio of 1:10], and boiled with intermittent stirring

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**Table 1.** Properties of milled rice cultivars.

| Rice cultivar | Crude protein (%) | Amylose content (%) | Gelatinization temperature (°C) | Alkali spreading value (score) | Gel consistency (mm) 30 min. | 60 min. |
|---|---|---|---|---|---|---|
| Kaohsiung Sen 7 (KSS7) | 9.0 | 25.1 | 68.0 | 1 | 38.0 | 38.4 |
| Taichung Sen 10 (TCS10) | 9.0 | 13.7 | 65.0 | 8 | 72.2 | 77.8 |
| Tainung 67 (TNu67) | 6.8 | 16.4 | 57.5 | 8 | 66.5 | 78.5 |
| Taichung waxy 46 (TCW46) | 7.5 | trace | 57.5 | 4 | 120.0 | 133.3 |

until the opaque core of the rice had just disappeared [2]. The rices were then collected on a stainless wire screen to drain the water. To obtain steamed samples, the rices were soaked in distilled water at 30°C for 3 hours, sealed in polyethylene bags, placed in a refrigerator overnight for tempering (the moisture contents were above 30%), and steamed in a covered bamboo pan over a boiling water bath until the opaque core had just disappeared. The same soaked and tempered rices were autoclaved at 121°C for 30 minutes to yield autoclaved samples. All the boiled, steamed and autoclaved samples were first cooled to room temperature and then freeze-dried. To obtain roasted samples, partial soaking was done by mixing calculated amounts of water with rice, and then tempering in sealed polyethylene bag for 3 days. The rices were adjusted to a series of moisture contents, 13%, 17%, 22% and 27%, then roasted by mixing with hot quartz sand (300°C) in an iron pan for 20 seconds (sand:rice ratio of 6:1) [34]. All samples were ground in a Udy Cyclo sample mill to pass through a 65 mesh screen.

**Analysis of milled rice**

Crude protein was determined by a micro-Kjeldahl method (N% x 5.95) [32]. Amylose contents of defatted rice flours were determined according to the improved method of Juliano *et al*. [22]. Amylose was measured by iodine colorimetry using potato amylose and defatted Taichung waxy 46 rice starch as standards. Viscoamylograms were run on a 10% (weight/volume, w/v, dry basis) sample suspension (500 ml) using a Brabender Viscoamylograph with a 700 cmg sensitivity cartridge at 75 rpm. Viscosity (B.U.) was recorded during a cycle consisting of heating (35°C to 95°C, at 1.5°C/min), holding (95°C for 20 minutes), cooling (95°C to 50°C, at 1.5°C/min), and holding (50°C for 20 minutes) [7]. Gelatinization temperature was measured by subtracting 3°C from the temperature of initial increase in viscosity on the viscoamylogram of 10% rice flour suspension [21]. Alkali spreading value was investigated by immersing six kernels in 20 ml of a 1.7% potassium hydroxide solution at room temperature for 24 hours and was calculated according to Bhattacharya's alkali reaction score [3]. The flours were analyzed for gel consistency of 100 mg flour (100 mesh) in 2 ml of 0.2 N potassium hydroxide. Its values were expressed as the gel length (mm) measured from the bottom of the test tube to the gel front after the cooled gels in 13 x 150 mm test tubes were maintained in horizontal position for 30 or 60 minutes [4].

**Physicochemical properties of processed samples**

The water absorption index (WAI) was determined according to the method of Anderson *et al*. [1] and calculated as the ratio of the weight of gel to the weight of the dry sample. Water solubility index (WSI, %) was measured as [(the dry weight in the supernatant) / (the dry weight of the sample) x 100]. Swelling power (SP) was defined as the ratio of the weight of gel to the weight of dry sample (100% - water solubility index, %).

The degree of gelatinization (DG) was measured using a β-amylase-pullulanase enzymic method [34]. Reducing sugars (as maltose) released from the digest (total carbohydrate) [12] were measured using Nelson's reagent [31]. Each test sample which was autoclaved at 121°C for 30 minutes was used as reference.

X-Ray diffraction patterns were determined using an X-ray diffractometer (Rigaku D/MAX-IIIA, Rigaku Keisoku Co, Ltd., Japan) with CuK$_\alpha$, radiation at 35 kV and 25 mA from 2$\theta$ = 30° to 4° [6].

Cross-sections of various processed samples were mounted on scanning electron microscopy (SEM) stubs with double-sided sticky Scotch tape, coated with gold (Ion coater IB-2, 20 nm) and examined with a Hitachi S-520 scanning electron microscope operated at 20 kV.

*In vitro* digestibility was measured according to the method of Holm *et al*. [14] with some modifications. To 1 ml suspension containing 1% wet-homogenized sample (100 mg sample in 10 ml 0.2 M phosphate buffer, pH 6.9) was added 1 ml of 15 units of a porcine pancreatic α-amylase preparation (one unit liberates 1 mg of maltose from soluble starch in 3 minutes at pH 6.9 and 20°C). After incubation at 37°C for 2 hours, the mixture was boiled for 10 minutes to inactivate the enzyme, filtered, and analyzed for the reducing sugar content using Nelson's reagent. The extent of hydrolysis was calculated as the percentage of maltose released per gram of the dry sample.

## Results and Discussion

### Properties of milled rice

Some physicochemical properties of four cultivars of milled rice are shown in Table 1. The protein contents in KSS7 and TCS10 rices were higher than those of the others which agreed with the results of the first crop of 1984 [6]. According to the amylose contents of defatted rice flour, the rices were classified into three categories [19]: (1) KSS7 - high amylose content rice (25.1%); (2) TCS10 and TNu67 - low amylose content rice (13.7-16.4%); and (3) TCW46 - waxy rice (trace of amylose). All rices belonged to the low gelatinization temperature rice (57.5-68.0°C). TCS10, TNu67 and TCW46 were classified as soft gels (72.2-120.0 mm) while KSS7 was hard gel (38.0 mm). KSS7 was less attacked by alkali than TCW46 whereas TCS10 and TNu67 were degraded easily.

### Water absorption index, water solubility index and swelling power

As shown in Table 2, the WSI of raw KSS7 was the lowest and TCW46 was the highest among the rice cultivars tested. However, their WAIs and SPs were similar. The WAI, WSI, and SP of KSS7 samples were also the lowest after thermal processing probably because, KSS7, with a high amylose content, is less easily solubilized [33]. At the same time amylose was less soluble than amylopectin [20]. Among the waxy samples, the WAI, WSI, and SP values for autoclaved and boiled ones were considerable higher than those for other samples. It was probably owing to the greater extent of modification of the starch granules during processing. WSI of all steamed samples was the lowest among the processed samples; it was even lower than that of the raw samples. WAI, WSI, and SP of roasted samples increased gradually as the moisture content of the rice kernel increased.

### Viscoamylograph viscosity

Considerable differences were obtained in viscosity profiles for the processed rice samples (Figs. 1 and 2). As shown in Fig. 1, the viscosity of raw non-waxy rice flours and waxy rice flour during heating stage was unstable and had a viscosity peak. However, the viscosity and the viscosity peak of the waxy rice flour were much lower than those of the same rice cultivar from the crops in 1982 [35] and 1984 [5]. In a separate experiment, the addition of AgNO$_3$ (1%, w/v) [15] to waxy rice flour suspension prior to the measurement gave a viscosity peak about 900 B.U. during heating in the viscoamylograph, indicating the large intrinsic amylase activity in this waxy rice [16]. Perhaps, its low viscosity is attributable to the environmental factors during cultivation. Autoclaved and boiled waxy samples exhibited higher initial viscosity values and showed a decline in viscosity during heating, probably owing to their high WAI, WSI, and SP values and degree of gelatinization. The viscosity of steamed waxy sample was somewhat lower than in the autoclaved and boiled samples and a

**Table 2.** Water absorption index (WAI), water solubility index (WSI), swelling power (SP), and degree of gelatinization (DG) of various rice samples.

| Material[a] | WAI[b] | WSI[b](%) | SP[b] | DG[c] |
|---|---|---|---|---|
| **KSS7 (Kaohsiung Sen 7)** | | | | |
| Raw | 2.35 | 1.69 | 2.39 | 29.71 |
| Autoclaved | 4.38 | 1.60 | 4.45 | 68.49 |
| Boiled | 5.06 | 1.64 | 5.14 | 72.55 |
| Steamed | 3.93 | 1.13 | 3.98 | 60.55 |
| Roasted-13% | 3.63 | 1.85 | 3.69 | 45.79 |
| Roasted-17% | 3.73 | 1.96 | 3.81 | 48.83 |
| Roasted-22% | 4.51 | 2.39 | 4.62 | 60.15 |
| Roasted-27% | 4.66 | 3.00 | 4.81 | 68.60 |
| **TCS10 (Taichung Sen 10)** | | | | |
| Raw | 2.55 | 2.36 | 2.61 | 43.98 |
| Autoclaved | 5.76 | 4.58 | 6.04 | 96.39 |
| Boiled | 5.59 | 2.32 | 5.73 | 85.63 |
| Steamed | 5.10 | 1.46 | 5.18 | 76.52 |
| Roasted-13% | 4.07 | 2.17 | 4.16 | 67.39 |
| Roasted-17% | 4.50 | 2.30 | 4.60 | 73.37 |
| Roasted-22% | 4.61 | 2.33 | 4.72 | 77.64 |
| Roasted-27% | 4.87 | 2.78 | 5.01 | 79.63 |
| **TNu67 (Tainung 67)** | | | | |
| Raw | 2.50 | 2.46 | 2.56 | 33.26 |
| Autoclaved | 5.60 | 5.75 | 5.95 | 100.00 |
| Boiled | 5.27 | 2.56 | 5.41 | 82.05 |
| Steamed | 4.25 | 1.92 | 4.33 | 72.23 |
| Roasted-13% | 4.28 | 2.51 | 4.39 | 56.61 |
| Roasted-17% | 4.42 | 2.69 | 4.54 | 59.74 |
| Roasted-22% | 4.76 | 2.92 | 4.90 | 70.96 |
| Roasted-27% | 4.68 | 3.46 | 4.85 | 79.11 |
| **TCW46 (Taichung waxy 46)** | | | | |
| Raw | 2.51 | 5.74 | 2.66 | 42.97 |
| Autoclaved | 15.78 | 34.61 | 24.13 | 100.00 |
| Boiled | 13.53 | 23.77 | 17.75 | 94.16 |
| Steamed | 9.17 | 5.05 | 9.65 | 93.78 |
| Roasted-13% | 4.81 | 4.09 | 5.02 | 64.62 |
| Roasted-17% | 5.36 | 4.90 | 5.64 | 65.01 |
| Roasted-22% | 6.83 | 7.10 | 7.35 | 80.81 |
| Roasted-27% | 8.68 | 7.72 | 9.40 | 90.13 |

[a]See text; the percentages for the roasted samples are the moisture contents. [b]2-4 replicate analyses on each material, the standard deviations (S.D.) were in the range 0.01-0.14. [c]4 replicate analyses on each material.

small viscosity peak was noticeable. The initial viscosity of non-waxy samples was lower than those of waxy samples owing to their low WAI, WSI and SP. None of the autoclaved and boiled non-waxy samples produced distinct viscosity peak and tended to be stable during holding at 95°C. It might be due to some degradation and structural modifications of the starch granules
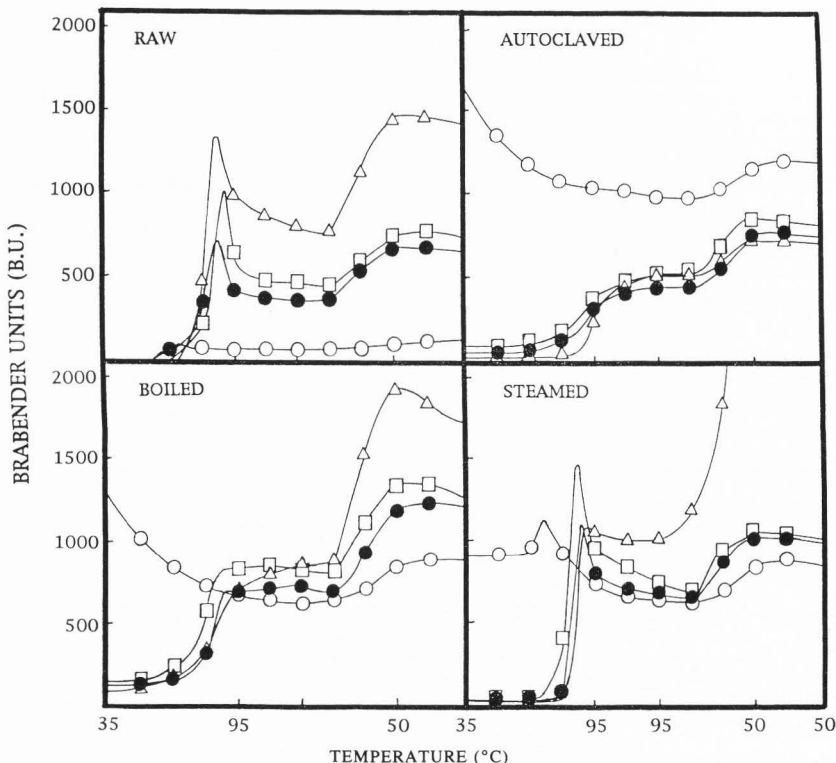
**Figure 1.** Brabender viscosity curves of various rice samples after different heat treatments. Viscosity (B.U.) was recorded during a cycle consisting of heating (35°C to 95°C, at 1.5°C/min), holding (95°C for 20 minutes), cooling (95°C to 50°C, at 1.5°C/min), and holding (50°C for 20 minutes). Kaohsiung Sen 7 (hollow triangles); Taichung Sen 10 (hollow squares); Tainung 67 (filled circles); and Taichung waxy 46 (hollow circles).

during processing. In steamed TCS10 and TNu67 samples, the viscosities during heating were unstable and rapidly decreased. On the contrary, the viscosity of steamed KSS7 sample during heating was stable. We are unable to explain why this happened. On the other hand, all viscosities increased during cooling and became stable during subsequent holding except with boiled KSS7 sample. An extremely high viscosity (> 2,000 B.U.) was found during cooling for the steamed KSS7 sample. The viscosity values of all boiled samples during heating and cooling cycle were higher than in the autoclaved samples. During

roasting with sand, the initial viscosity of the waxy samples increased in general, but the viscosity peak and viscosities during the heating and cooling cycle decreased gradually with each increment in the moisture content of the rice (Fig. 2). Thus, the roasted waxy samples showed pregelatinization as well as some degradation (dextrinization) as the moisture content was increased. This was also confirmed by a higher WSI and a higher degree of gelatinization. The stable viscosity values at varying temperatures of the roasted waxy rice containing 27% water was similar to popped Louisiana-grown Bluebonnet rice containing 6%
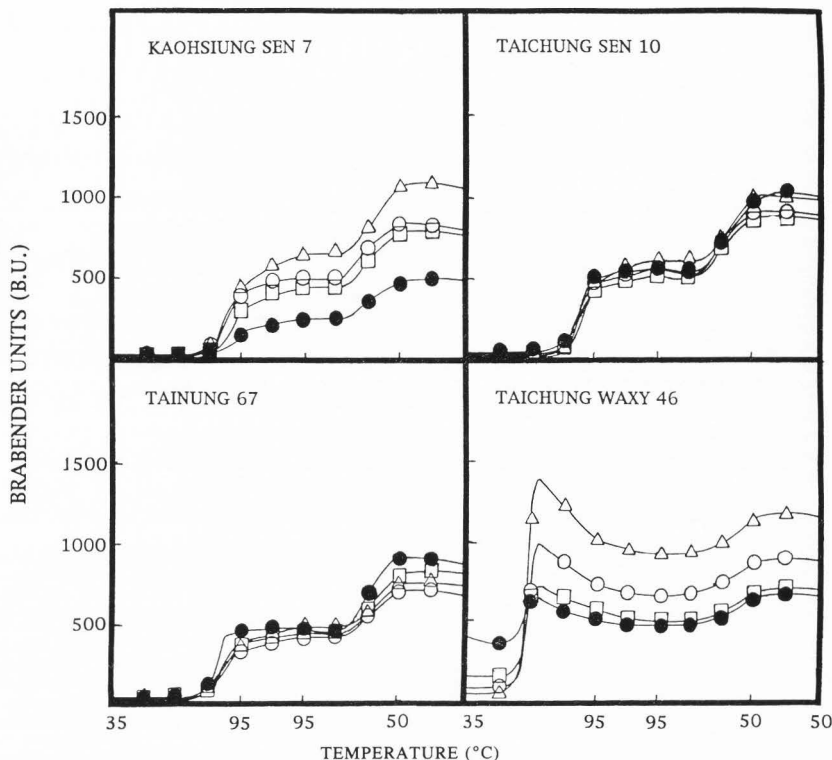
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**Figure 2.** Brabender viscosity curves of various roasted rice samples with different moisture contents: 13% (hollow triangles); 17% (hollow circles); 22% (hollow square); and 27% (solid circles).

of added water [26]. In roasted non-waxy samples, the initial viscosity was low, the viscosity values were stable during holding at 95°C and increased during cooling. In the KSS7 samples, the viscosity during the heating and cooling cycle markedly decreased as the moisture contents increased. However, there was no such apparent difference between the TCS10 and TNu67 samples. Further studies on the molecular size distribution and properties of starch in processed rice samples are underway.

**Degree of gelatinization (DG)**

As shown in Table 2, the DG of rice samples increased after thermal processing as compared to the raw samples. The DG of rice samples was different under various thermal processing conditions. Of the processed samples, the high-amylose KSS7 rice had the lowest DG in each treatment. The DG values of steamed samples were

lower than those of autoclaved and boiled samples. Johnson *et al.* [18] observed that, in corn (with a moisture content of 12-13%), steaming resulted in a negligible extent of gelatinization. During the sand-roasting process, the DG of the samples increased gradually as the amount of moisture present was raised. It was shown that the gelatinization of starch was limited when the moisture content was limited, even when the samples were heated at a high temperature (300°C). As the moisture content was raised to a sufficient level, the heating temperature played a major role. Furthermore, differences among the rice cultivars were also an important factor.

**X-Ray diffraction patterns**

X-Ray diffraction patterns of various rice flours under different thermal processing conditions are shown in Figs. 3 and 4. All non-waxy boiled samples had a near V-
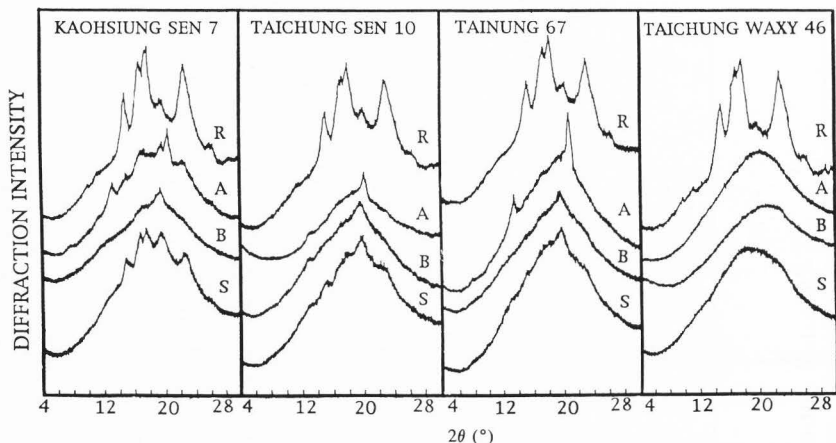
**Figure 3.** X-ray diffractograms for raw (R), autoclaved (A), boiled (B) and steamed (S) rice samples.

pattern as indicated by peaks at $2\theta = 19.8°$ and $12.8°$, though the value at $2\theta = 12.8°$ in TNu67 and KSS7 samples was attenuated. Some peaks in non-waxy rice samples were noticeable even after autoclaving and steaming. The steamed samples were shown to have a larger number of discernible peaks of A-pattern and V-pattern than the autoclaved samples, especially in KSS7 samples. In non-waxy autoclaved samples, a new peak appeared near $2\theta = 20.6°$. However, all the waxy samples revealed an amorphous spectrum similar to popped Asm 44 waxy rice [29] and extruded waxy corn starch [25]. In the roasted samples, when the moisture content of the rice was increased, the intensities of some peaks decreased or the peaks disappeared ($2\theta = 10.0°$, $11.6°$, $15.0°$, $17.0°$, $17.8°$, $22.8°$, $26.0°$), while the V type peaks ($2\theta = 12.8°$ and $19.8°$) increased as shown in Fig. 4.

**Extent of digestibility**

Data on digestibility of processed rice samples by pancreatic $\alpha$-amylase measured as the release of reducing sugars are presented in Table 3. Digestibility increased after thermal processing and over 50% of the starch was hydrolyzed within 2 hours except for the roasted KSS7 samples with low moisture contents of 13% and 17%.

**Scanning electron microscope examination**

As shown in Fig. 5, KSS7 rice kernel appeared somewhat enlarged after each thermal processing. The boiled sample was the most expanded one among all samples and a gel-like flaky structure was apparent. Besides, many fissures were found around the outside of the kernel. In roasted samples, some fissures were also found but not as many as in the boiled sample.

Micrographs obtained with the central part of cross-sections of the processed KSS7 rice samples are shown in Fig. 6. The starch granules appeared to be compactly packed before processing. In the case of autoclaving, a gel-like substance and some granular matrix were seen. After boiling, the granular matrix was largely disrupted and appeared flaky. In steamed sample, the starch granules seem to be partially gelatinized and packed together. In roasted rice kernels with different moisture content, the starch granules gradually gelatinized and melted substance appeared. The micrographs of processed samples of the other rice cultivars are not shown here since their structure was similar to KSS7.

**Conclusion**

When rice kernels were thermally treated by different methods, the physicochemical properties of the processed samples of various cultivars were different. From the results presented, the waxy rice samples were more highly gelatinized than non-waxy samples during the processing, especially in the samples with optimal moisture contents, and at high temperatures. The effect of moisture content of the rice seems more significant than the heating temperature. The amylose contents of the rice may be the most important factor. The thermal degradation of starch in these processed samples is under further study.

**Acknowledgement**

Processing properties of rice

**Table 3.** In *vitro* digestibility (%) of rice samples.

| Material[a] | KSS7[b] | TCS10[b] | TNu67[b] | TCW46[b] |
|---|---|---|---|---|
| Raw | 21.15 | 38.04 | 39.82 | 53.40 |
| Autoclaved | 55.22 | 55.32 | 54.85 | 63.37 |
| Boiled | 55.29 | 53.58 | 54.63 | 56.92 |
| Steamed | 52.55 | 53.20 | 56.40 | 56.98 |
| Roasted-13% | 45.77 | 55.05 | 56.12 | 51.38 |
| Roasted-17% | 46.18 | 56.61 | 56.84 | 50.12 |
| Roasted-22% | 55.86 | 57.23 | 62.09 | 54.48 |
| Roasted-27% | 58.81 | 60.55 | 63.53 | 55.47 |

[a] See text.
[b] KSS7: Kaohsiung Sen 7; TCS10: Taichung Sen 10; TNu67: Tainung 67; TCW46: Taichung waxy 46.
[c] Mean of two experiments and 4 analyses in each experiment. The S.D. were in the range 0.35-2.01.

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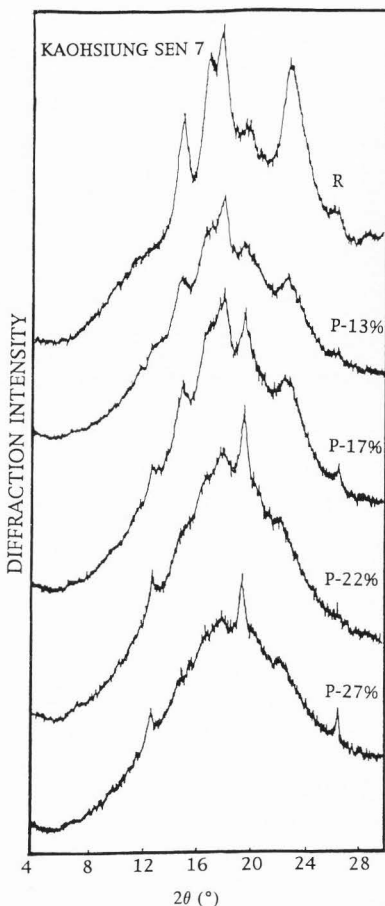
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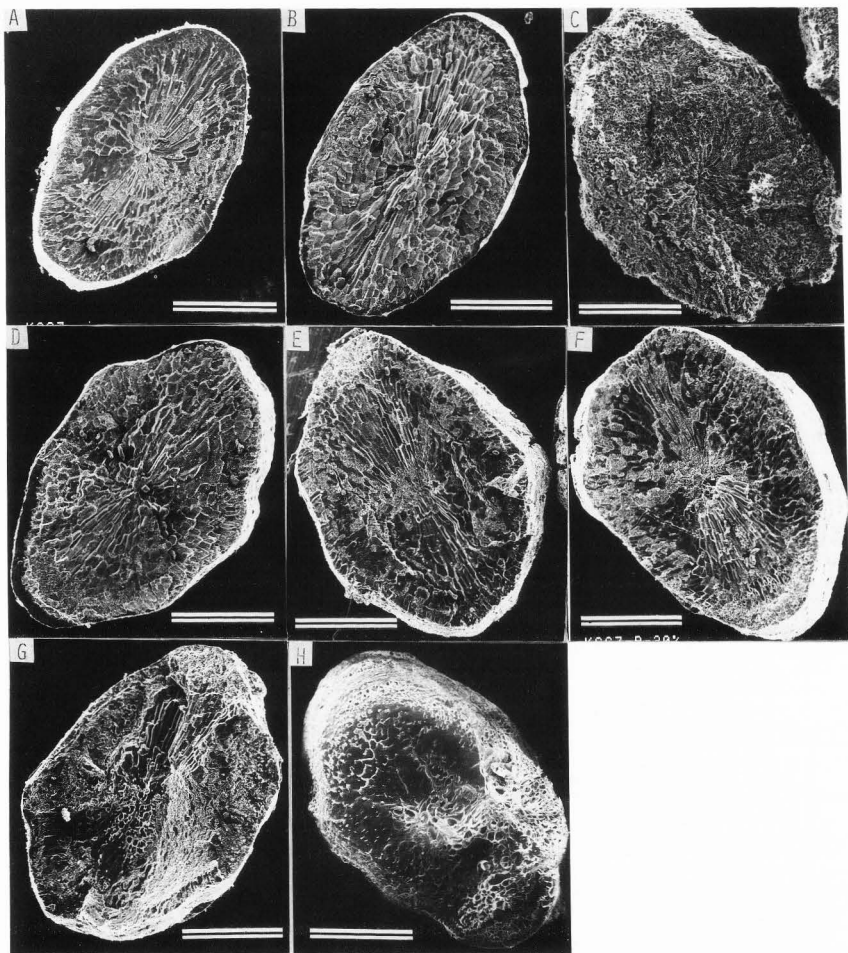
**Figure 4.** X-ray diffractograms of raw (R) and roasted (P) rice samples with different moisture contents.

**Figure 5.** Scanning electron micrographs of cross-sections of Kaohsiung Sen 7 (KSS7) rice subjected to different thermal treatments. **A**: milled rice; **B**: autoclaved; **C**: boiled; **D**: steamed; **E**: roasted (at 13% moisture content); **F**: roasted (at 17% moisture content); **G**: roasted (at 22% moisture content); **H**: roasted (at 27% moisture content). Fig. A, B, and D-H are at same magnification (bar = 750 $\mu$m); in C: bar = 860 $\mu$m.
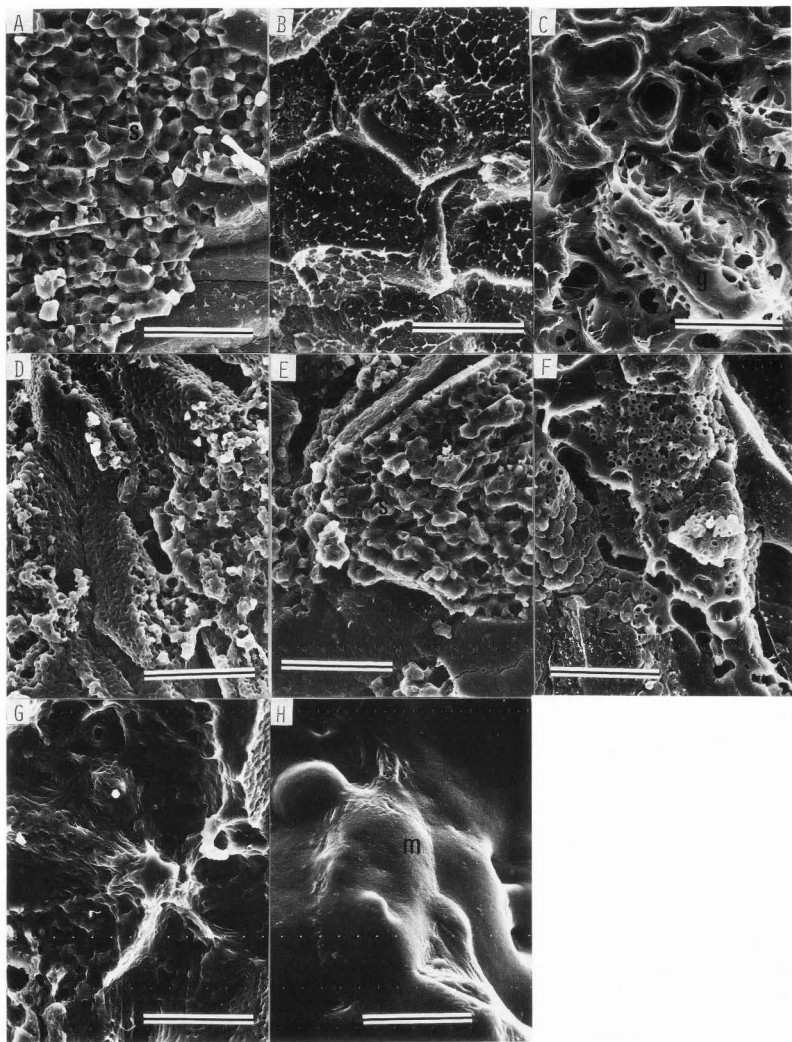
**Figure 6.** Scanning electron micrographs of the central part of cross-sections of milled and processed Kaohsiung Sen 7 (KSS7) rices. **A**: milled rice; **B**: autoclaved; **C**: boiled; **D**: steamed; **E**: roasted (at 13% moisture content); **F**: roasted (at 17% moisture content); **G**: roasted (at 22% moisture content): **H**: roasted (at 27% moisture content). s: starch granule; g: gel-like substance; m: melted starch. All figures at same magnification (bar = 50 μm).

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## Discussion with Reviewers

**R. Chinnaswamy**: Literature reports clearly indicate lipid-amylose complex formations in steam-cooked rices. Are your results in agreement with those studies and how?

**Authors**: According to the literature, lipid-amylose complex formation would lead to the appearance of a V-pattern, two peaks around 20° and 13° in the X-ray diffractogram. Based on our results, the lipid-amylose complex formations were apparent in steamed non-waxy samples though the peak at 12.8° was greatly reduced.

**R. Chinnaswamy**: How do you arrive at the optimum puffing conditions of 300°C for 20 seconds in a preheated sand with 1:6 rice to sand ratio?

**Authors**: An appropriate quantity of sand was put in a iron pan to preheat on fire with mixing. A temperature sensor was inserted into the sand. When the temperature reached 300°C, the weighed rices were poured in and mixed thoroughly. After 20 seconds, they were poured immediately into a large sieve to filter out the sand.

**R. Chinnaswamy**: In Table 2, the WAI, WSI, SP and DG are much higher for waxy than non-waxy rices. How do you explain this behavior?

**Authors**: It might be attributed to the greater extent of modification of starch structure in waxy rice under processing.

**B.J. Juliano**: *In vitro* digestibility test used less $\alpha$-amylase than Holm *et al.* (1985) and percent hydrolysis is lower than Holm's values for wheat starch even after correction for non-starch fraction of milled rice. Why was less $\alpha$-amylase used?

**Authors**: The amount of $\alpha$-amylase used and the experimental conditions such as hydrolysis time were determined based on our preliminary experiments. Since the reaction conditions and the tested samples were different from those used by Holm, our results, such as enzyme concentration requirement and hydrolysis percent, were observed to vary from what he reported. Actually, low enzyme concentration (such as 200 units/g of starch) was also used by Holm in another paper (Holm J, Björck I. Effects of thermal processing of wheat on starch: II. Enzymic availability. J. Cereal Sci. **8**: 261-268, 1988).

**B.J. Juliano**: The steamed non-waxy samples were not completely gelatinized as shown by amylograms and X-ray diffraction. Are the samples similar to parboiled rice?

**Authors**: Since we are not very experienced in the preparation and properties of parboiled rices, it is difficult for us to compare them with our tested samples.