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Comparative Studies on the Physicochemical Properties and Microstructure of Raw and Parboiled Rice

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ABSTRACT

The protein and mineral salts of rice were found to have increased while water-soluble substances were found to have decreased as a result of parboiling. Parboiling resulted in marked changes in the amylograph properties of rice paste, as well as increasing its resistance to alkali dispersion. The grains were shorter but wider, with lower water absorption and swelling capacity during cooking than those of raw-milled rice.

The differences in ultrastructure between dry and cooked raw-milled and parboiled rice were studied with a scanning electron microscope. Complete deformation of the starch granules was evident in the raw-milled rice after cooking for 9×10^2 and 12×10^2 s, while those of parboiled rice showed great resistance to deformation. Variations in the over-cooked grains of both raw-milled and parboiled rice were studied.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important food crops in Egypt. White milled rice is the final product, comprising about 70 % of the grain after removal of the bran, germ and aleurone layer. The amount of bran and aleurone layer removed affects the nutritive value of the milled rice

(Kennedy, 1980). Normand *et al.* (1966) reported that the highest concentration of vitamin B complex was in the outer portions of the endosperm, decreasing toward the center of the rice kernel and that milling resulted in the loss of more than 50% of the vitamin B content. Juliano (1972) found that rice bran was higher in protein, fat and mineral salts than the endosperm.

Improvement of the nutritional value of rice through parboiling is a well-established process. The long and slender rice varieties are usually parboiled because they are fragile compared with the short-grain ones (Ali & Ojha, 1976). The changes in the rice grain caused by parboiling are mainly physical rather than chemical and are closely related to the techniques used (Juliano *et al.*, 1973). Padua & Juliano (1974) indicated that thiamin and possibly fat and protein were redistributed in the rice grain during parboiling. Varietal differences in the parboiling of rough rice have recently been reported in such properties as optimum water temperature during pre-soaking (Bhattacharya & Subba Rao, 1966) and the reduction of the starch iodine blue color and amylose content (Kamal *et al.*, 1963).

This work was carried out to study the effect of parboiling on some physicochemical characteristics and on the ultrastructure of long-grain rice.

MATERIALS AND METHODS

Philippini long-grain paddy rice from the 1982 crops, to be used for the preparation of parboiled rice, was obtained from the Center of Rice Research and Technology, Semoha-Alexandria.

Preparation of parboiled rice

The method of parboiling used in this work was chosen from the preliminary experiments leading to maximum yield of milled rice with minimum quantities of broken grains for the chosen variety. Clean paddy rice (0·5 kg) was steeped in water at 65 °C for $12{\cdot}6 \times 10^4$ s, drained and wrapped in aluminum foil, and steamed immediately in an autoclave for 3×10^2 s at 69 kP until the husk on the grain split. The grains were then air-dried at room temperature in the absence of direct sunlight to avoid any stress on the kernels. 0·1 kg of the dry parboiled rice (13·02% moisture content) were milled using a laboratory rice mill (Vercelli, Italy).

Analytical procedures

Moisture, crude protein and ash of ground rice were determined as described by the AOAC (1975). Ca, Fe and Mg were determined using a Perkin Elmer atomic absorption spectrophotometer, Na and K by the flame photometer (AOAC, 1975) and phosphorus by the colorimetric method of Allen (1940). The amount of water-soluble substances was determined by extracting 0·005 kg of the ground rice sample with 50 ml of distilled water at 30 °C for $3{\cdot}6 \times 10^3$ s and measuring the solids by drying the extract at 105 °C.

Physical tests

The mean length and width of full-length grains of raw-milled, parboiled and cooked rice were determined using a micrometer. The alkali spreading and clearing test on the whole milled rice grain was carried out according to the procedure of Simpson *et al.* (1965). Water absorption and swelling capacity were determined by cooking 0·01 kg of rice in 70 ml of boiling distilled water for 6×10^2, 9×10^2, 12×10^2, and 18×10^2 s, draining the excess water, and determining the increase in weight and volume of the grains. Volume of the grains was measured by displacement of water. Water absorption was expressed as milliliters of water absorbed by 0·001 kg of rice, and the swelling capacity as the ratio of final to the initial volume of rice.

Gelatinising and pasting characteristics of ground rice were measured with the Brabender amylograph using the method of Halick & Kelly (1959). Gelatinization time was reported as the number of seconds required to reach peak viscosity from the first perceptible increase in viscosity.

Scanning electron microscopy (SEM)

Dry raw and cooked rice samples were fractured near the centre of the grain and mounted on aluminum stubs with Duco cement and coated with 150Å thick gold in a vacuum chamber before observation with the SEM (Jeol–JSM, 25 SII, Tokyo).

RESULTS AND DISCUSSION

Results presented in Table 1 show that parboiling slightly increased the protein content of raw-milled rice. Houston *et al.* (1964) found that parboiled rice grains became harder in the presence of the outer layers (polishings, which have a high protein content). These were quite difficult to remove during milling. The increased ash content of parboiled rice might be due to the water-soluble mineral salts which penetrated throughout the grain during the steeping and steaming processes. Roberts (1979) found that the milling process affected the mineral content of rice.

TABLE 1
Effect of Parboiling on Properties and Composition of Rice

Property	*Raw-milled rice*	*Parboiled rice*
Crude protein (%N × 5·95)	7·67	8·14
Ash (%)	0·39	0·44
Na (mg/0·1 kg)	7·28	11·75
Ca (mg/0·1 kg)	16·01	23·20
K (mg/0·1 kg)	97·0	121·1
P (mg/0·1 kg)	84·2	127·0
Mg (mg/0·1 kg)	28·33	40·04
Fe (mg/0·1 kg)	1·21	1·27
Water-soluble substances (%)	1·37	0·91

Minerals such as Na, Ca, Fe, Mg, Cu, Mn and Zn were present in the hulls and the outer bran layer, removed during the milling process (Kennedy, 1980). The six mineral elements analyzed accounted for 60·0 % and 73·7 % of the total ash content of raw-milled and parboiled rice, respectively. Phosphorus and potassium constituted the bulk of the ash. Parboiling increased the concentration of the minerals in rice without any change in the iron content.

The amount of water-soluble substances, which approximated the combined amounts of water-soluble carbohydrates and proteins, was higher in raw-milled rice than in parboiled rice. Padua & Juliano (1974) stated that the increased hardness of the endosperm probably reflected the greater adhesion/cohesion between starch granules and protein bodies in parboiled rice. Dimopoulos & Muller (1972) reported that during parboiling the protein substances were separated and sank into the compact mass of gelatinized starch, becoming less liable to extraction. Thus the rice–protein interaction and/or retrogradation of starch explain the reduced soluble substances in the parboiled rice.

Alkali spreading and clearing values are terms representing the reaction of white rice kernels to soaking in dilute alkali and indicate the textural qualities in the cooked rice (Simpson *et al.*, 1965). Data in Table 2 show the lower alkali spreading and clearing in parboiled rice compared with raw-milled rice. The resistance of parboiled rice to dispersion in the alkali

TABLE 2
Alkali Test and Amylogram Data of Raw-Milled and Parboiled Rice

Property	*Raw-milled rice*	*Parboiled rice*
Alkali test values		
Spreading	6·3	4·6
Clearing	5·7	4·0
Amylograph properties		
Gelatinization temperature (°C)	67·5	70·0
Gelatinization time (s × 10^2)	6·5	7·8
Peak viscosity (BU)[a]	655	610
Breakdown (BU)	505	585
Setback (BU)	730	815

[a] BU = Brabender unit.

test might be related to the hardness of the grain as a result of the retrogradation of gelatinized starch. Raghavendra Rao & Juliano (1970) reported that parboiling made the milled rice more resistant to disintegration, reflecting its greater resistance to burst during cooking.

Parboiling resulted in interesting changes in the amylograph curve of rice paste (Table 2). The gelatinization temperature and time of parboiled rice were generally higher than in raw-milled rice. The longer gelatinization time for the parboiled rice might be largely due to the reduced swelling ability of starch granules. A markedly lower peak viscosity was noted in the parboiled sample than in the raw-milled rice. The drop in amylograph peak viscosity resulting from parboiling was ascribed by Kamal *et al.* (1963) to a higher amylase activity in parboiled rice. On the other hand, conditions during the steaming phase of parboiling were severe enough to inactivate any amylases present. Thus

TABLE 3
Changes in Dimensions, Water Absorption and Swelling Capacity of Raw and Parboiled Rice During Cooking

Cooking time ($s \times 10^2$)	*Raw-milled rice*				*Parboiled rice*			
	Length (mm)	*Width (mm)*	*Water absorption (ml/0·001 kg)*	*Swelling capacity*	*Length (mm)*	*Width (mm)*	*Water absorption (ml/0·001 kg)*	*Swelling capacity*
0	5·86	2·36	—	1·0	5·63	2·49	—	1·0
6	6·80	2·44	2·10	3·10	6·20	2·55	1·56	2·4
9	7·22	2·53	2·24	3·23	6·51	2·67	2·0	3·11
12	8·50	2·64	2·82	3·87	7·34	2·90	2·23	3·6
15	8·71	2·80	3·12	4·19	7·66	3·12	2·55	4·0
18	9·42	2·92	3·30	4·66	8·31	3·40	2·61	4·4

the greater extent of retrogradation in the parboiled rice might help to explain its low and delayed peak viscosity, reflecting greater resistance to breakdown. The viscosity on cooking at 94 °C for 12×10^2 (breakdown), relative to peak viscosity, was generally lower and the final viscosity on cooling to 55 °C (setback) was higher in the parboiled sample than in raw-milled rice.

The results in Table 3 show that parboiling caused some minor but distinct changes in the dimensions of the rice grain. The average length of the parboiled rice was less while the width was more than those of the raw-milled rice. The cooked parboiled rice grains were shorter but wider than the cooked raw-milled rice after the same cooking time. The relatively greater expansion of parboiled rice width after cooking gives it a characteristic short and plump appearance.

The water absorption and swelling capacity were low for parboiled rice compared with raw-milled rice for the same periods. The raw-milled rice required $9–12 \times 10^2$ s to become fully cooked (as indicated by taste panelists), while parboiled rice needed 18×10^2 s to be cooked to the same degree of softness. Raw-milled rice cooked beyond 12×10^2 s continued to absorb more water but the grains lost their shape becoming soggy, then bursting and becoming pasty (Fig. 1). On the other hand, parboiled rice could be cooked for the same period of time without losing its shape. Parboiling which causes gelatinization hardens the grain, which consequently needs a longer time to cook to a soft consistency without disintegration of the cell walls.

In raw-milled rice the ultrastructure of the compound nature of starch bodies of the endosperm was evident and well defined (Fig. 2). The polygonal shapes of the compound starch granules (CS) were composed

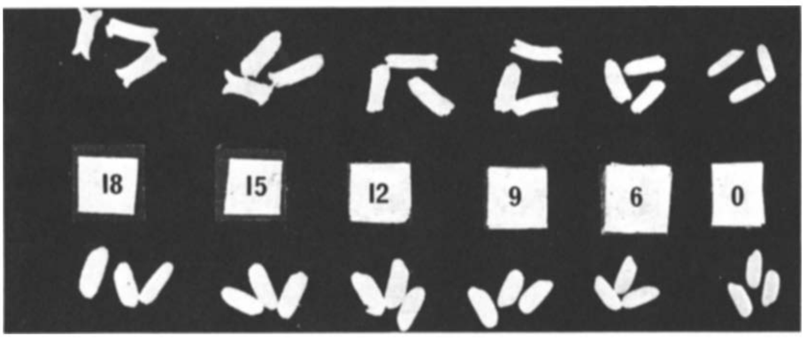


Fig. 1. Raw-milled and parboiled rice samples cooked for different periods ($s \times 10^2$).

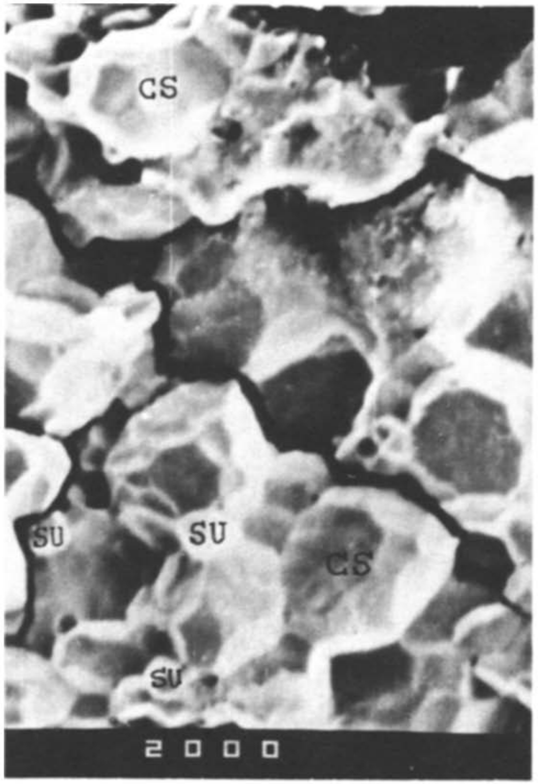


Fig. 2. SEM micrograph of raw-milled rice endosperm. CS = compound starch granule; SU = starch unit.

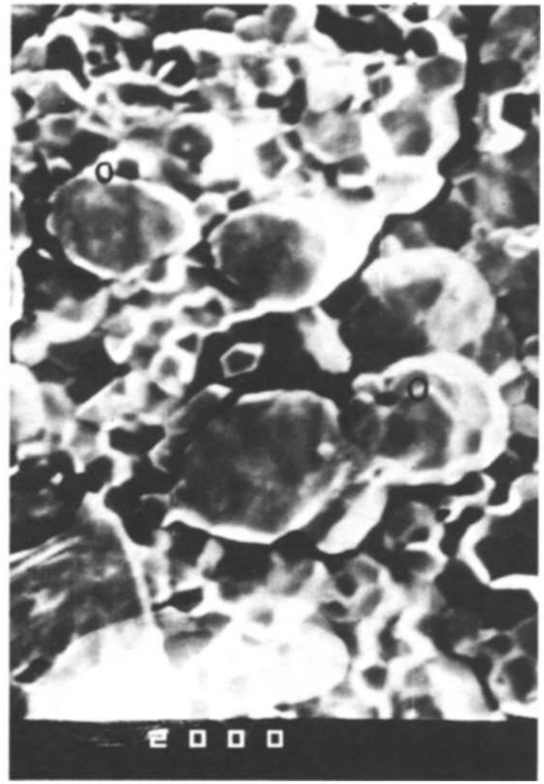


Fig. 3. SEM micrograph of parboiled rice endosperm. O = Pit holes due to α-amylase activity.

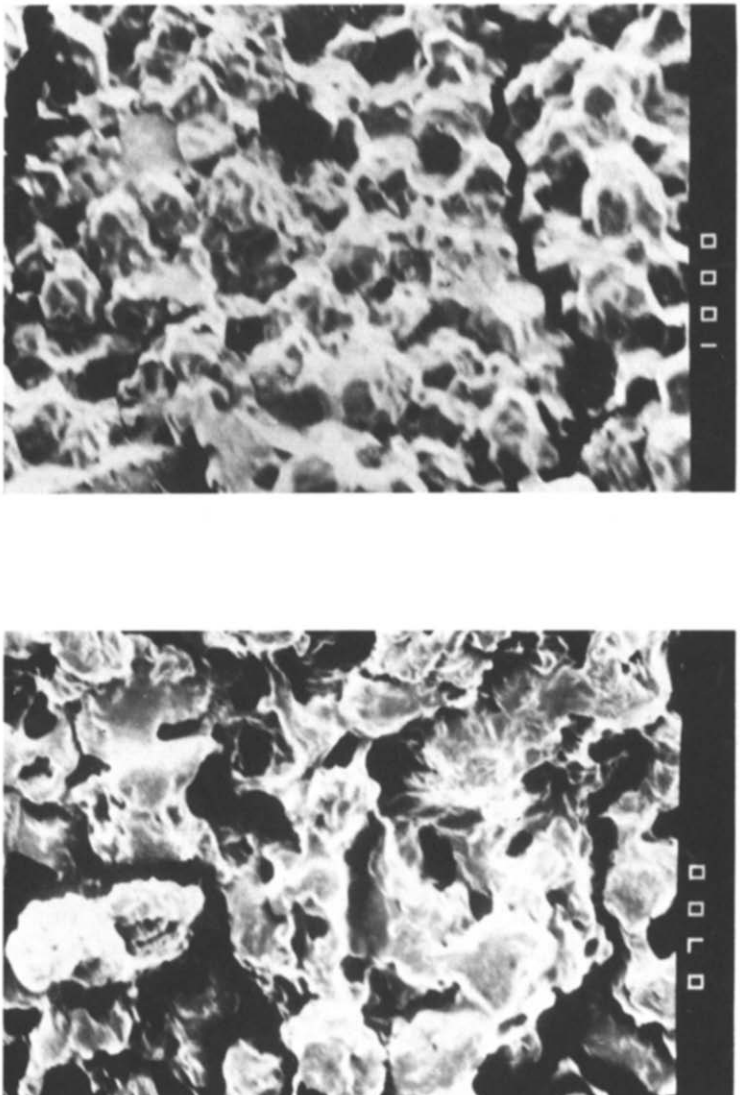
of several smaller units (SU) with individual intact walls, shown when the compound granules were fractured by pressure. Juliano (1972) reported that rice starch granules were polygonal with the structure of a pentagonal dodecahedron, and suggested that the polyhedral form might be caused by the compression of starch granules during development. Figure 3 shows a marked difference in the appearance of the starch granules in the parboiled rice endosperm, being partially gelatinized and degraded in size to various degrees. The α-amylase activity was evident by the pitting of the starch granules as suggested by Watson & Dikeman (1977). However, there appears to be a residual core of ungelatinized starch in the middle of the granules.

It is apparent in raw-milled rice cooked for 6×10^2 s that the starch granule gelatinization has progressed inward towards the center with volume expansion and splitting of granule walls leaving a residual core of ungelatinized starch (Fig. 4(a)). In comparison, no significant difference existed in the shape of starch granules of parboiled rice cooked for the same time except for the appearance of numerous irregular protuberances (Fig. 4(b)). The low water absorption and diminished swelling capacity of parboiled rice might explain its resistance to change during cooking.

Cooking of raw-milled rice for an additional 3×10^2 s (Fig. 5(a)) resulted in a continued swelling and gelatinization of the starch granules as a whole with complete deformation of the granule shape as well as ruptured walls. Although parboiled rice grains had undergone a considerable degree of swelling at this time (9×10^2 s), the walls of starch granules remained relatively intact and resistant to deformation (Fig. 5(b)).

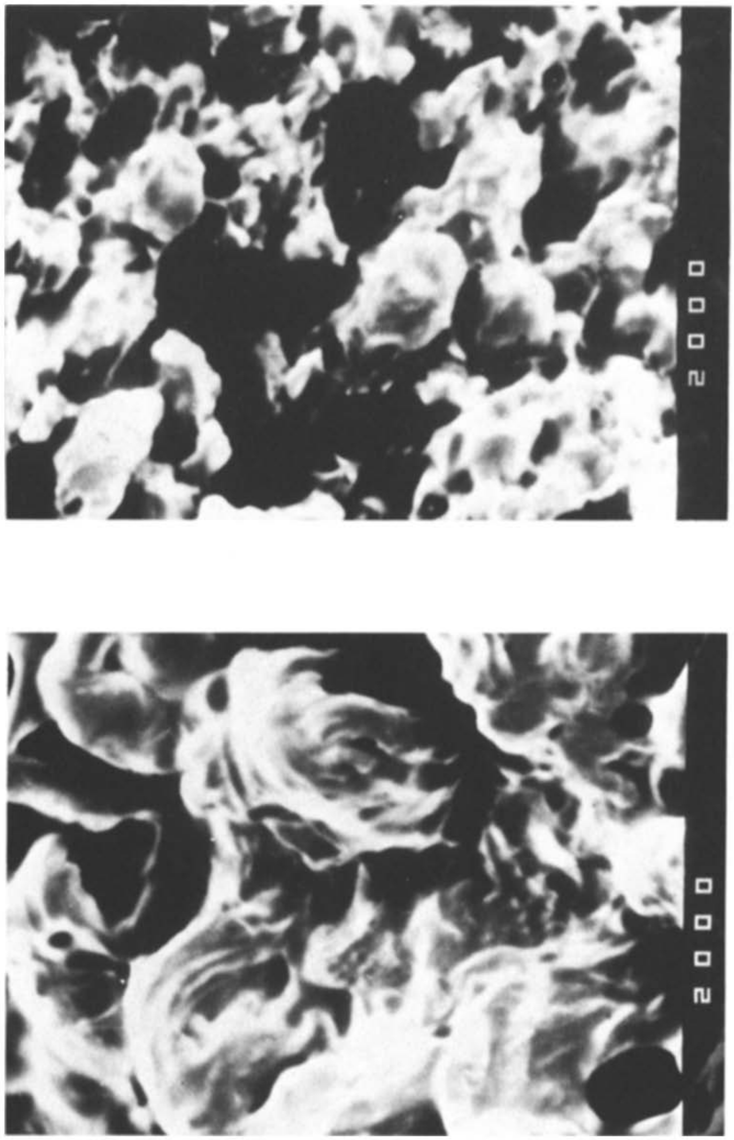
It is evident in Fig. 6(a) that all the starch granules have gelatinized after 12×10^2 s cooking with the dispersion of the starch suspension in the case of raw-milled rice. In parboiled rice the rupture of starch granule walls began to show with the diffusion of the starch suspension (Fig. 6(b)). However, some starch granules still retained their integrity and shape. Completely gelatinized granules appeared as ghost-like structures with distinguishable walls (Fig. 7(a)). This was evident in the over-cooked raw-milled rice (18×10^2 s). In parboiled rice cooked for 18×10^2 s (Fig. 7(b)), the diffusion and dispersion of starch granules as a whole occurred with complete deformation of the shape of the granules.

The conclusion might be drawn that rice parboiling, besides raising the nutritive value of the grain with respect to protein, vitamins and minerals, exerts a marked effect on improving the milling quality.



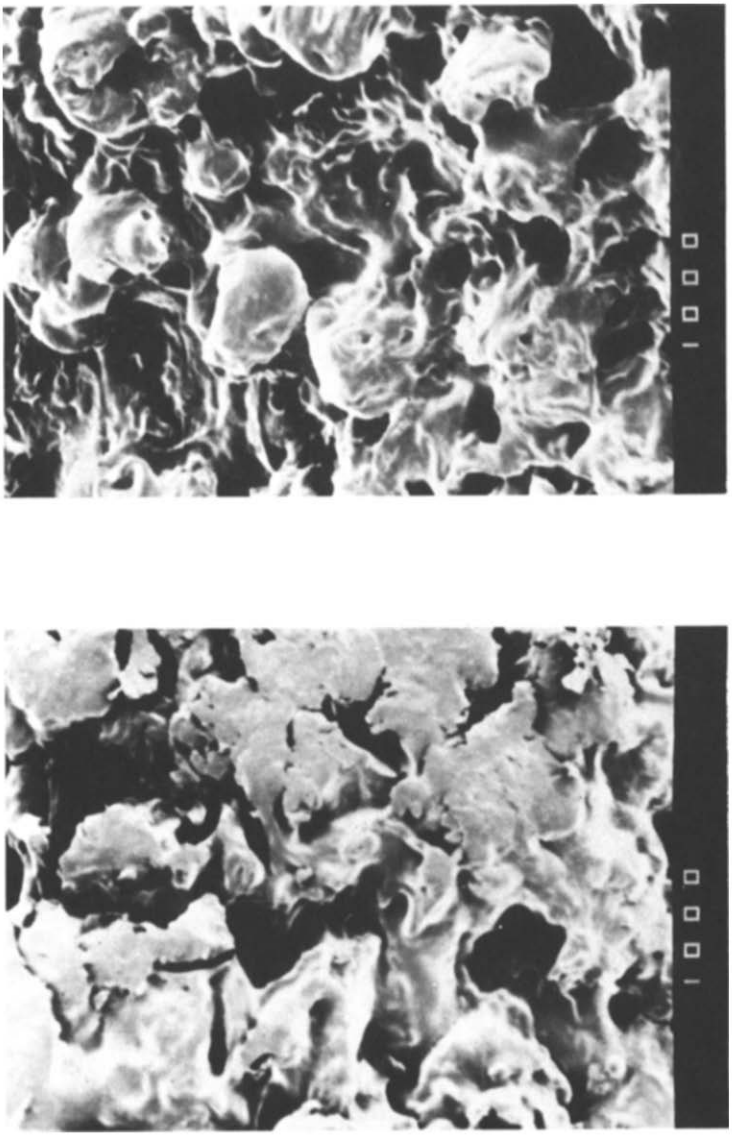
(a) (b)

Fig. 4. SEM micrograph of (a) raw-milled rice and (b) parboiled rice both cooked for 6×10^2 s.



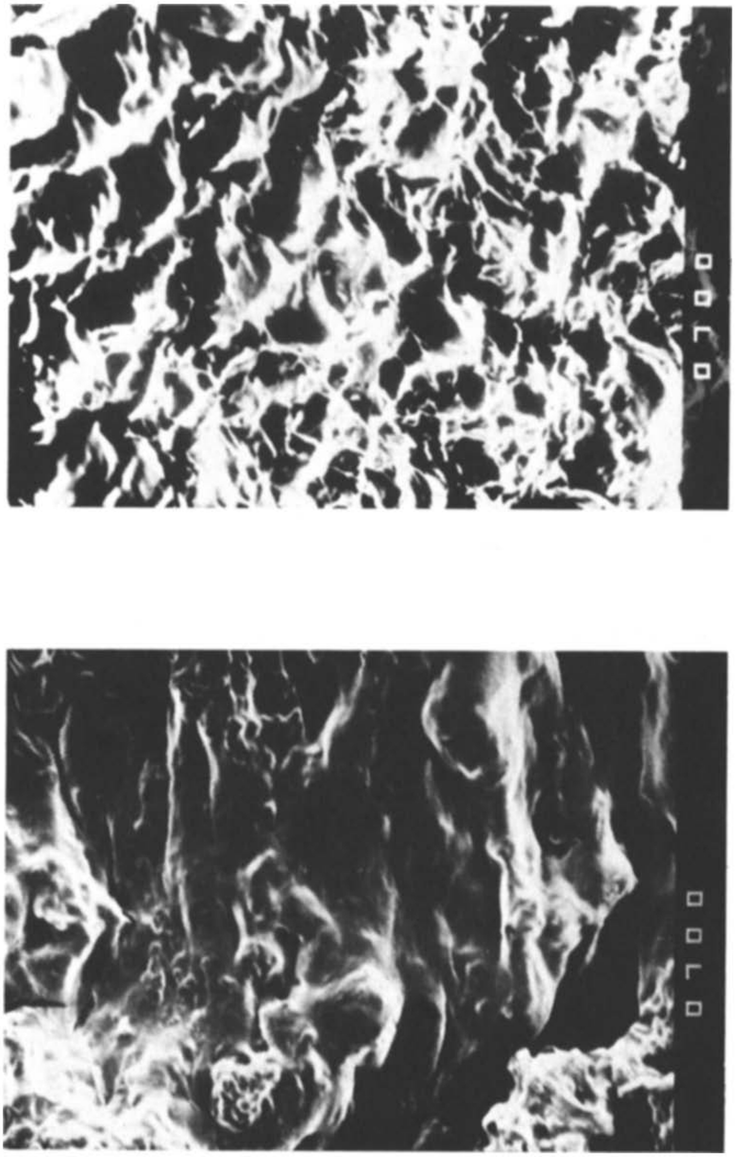
(a) (b)

Fig. 5. SEM micrograph of (a) raw-milled rice and (b) parboiled rice both cooked for 9×10^2 s.



(a) (b)

Fig. 6. SEM micrograph of (a) raw-milled rice and (b) parboiled rice both cooked for 12×10^2 s.



(a) (b)

Fig. 7. SEM micrograph of (a) raw-milled rice and (b) parboiled rice both cooked for 18×10^2 s.

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