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Textural and morphological changes of Jasmine rice under various elevated cooking conditions

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Abstract

The effects of cooking at elevated temperatures (80, 100, 120 and 140 °C) and pressure levels (0, 0.1, 0.3 and 0.5 MPa) on the textural and morphological properties of cooked Jasmine rice were investigated. The developed high pressure cooker was utilized to process Jasmine rice in excess water under isothermal conditions. Rice cooking at higher temperature produced softer and stickier grain texture as well as more off-white colour. Using scanning electron microscopy technique, the microstructure revealed that the soft texture at high cooking temperature corresponded well to the increase of pore size and thickness of the sponge-like texture of inner layer endosperm. As the temperature increased, the outer layer of cooked rice became less porous. Boiling significantly altered the external appearance (namely colour and exterior integrity) and texture of cooked rice while cooking pressure had a little or no effect.

Keywords: Jasmine rice; Cooked rice; Texture; Morphological properties

1. Introduction

Khao Dawk Mali (KDML) 105 is one of the most popular rice varieties in Thailand. Owing to its pleasant aroma, white colour and soft texture, the KDML 105 Thai aromatic rice cultivar is commonly referred to as "Jasmine rice". In Thailand, Jasmine rice is considered as a vital crop for domestic consumers and a primary export commodity for economic growth (Sarkarung, Somrith, & Chitrakorn, 2000; Chitrakorn, 2003). Jasmine rice can be consumed in many ways, for example whole grain consumption. Some Asian peoples cook their rice in an ample amount of water to obtain desirable texture whereas, in many western cultures, rice is boiled in excess water until the centre of the grain is fully cooked (Juliano, 1982). Texture and physical appearance of cooked rice may vary, depending on the method of cooking.

Several research groups have associated cooking conditions with the textural changes. Rice cooking, using isothermal calorimetry at various temperatures (30–120 °C), illustrated structural changes induced by water diffusion during starch gelatinization of whole rice kernels (Riva, Schiraldi, & Piazza, 1994). Ong and Blanshard (1995) studied final texture of cooked parboiled rice from 11 different cultivars of *indica*, non-waxy rices and found that the change of amylose content had a greater impact on the texture of the cooked rice than did physical attributes (e.g. granule morphology, crystallinity and size distribution). Watanabe, Arai, Honma, and Fuke (1991) improved the cooking properties of aged rice grain by pressurization in soaking step before cooking. This result showed the effects of pressurization in improving the properties of cooked rice, for example, brightness, flavour and texture. The application of elevated pressure during parboiling created darkening of the finished product and affected consumer acceptability (Bhattacharya & Rao, 1966; Luh & Mickus, 1991).

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Many studies have reported relationships between physicochemical properties and texture of cooked rice (Sowbhagya, Ramesh, & Bhattacharya, 1987; Reddy, Ali, & Bhattacharya, 1993; Martin & Fitzgerald, 2002; Champagne et al., 1998; Hamaker & Griffin, 1990; Juliano, Onate, & del Mundo, 1965). The qualities of cooked parboiled rices have been shown to be related to cooking conditions (Bhattacharya, 1996; Islam, Shimizu, & Kimura, 2004). Several researchers have studied the texture of cooked rice and employed sensory tests to study the eating quality of cooked rice (Yau & Huang, 1996; Okabe, 1979; Perez, Juliano, Bourne, & Anzaldua-Moralcs, 1993). To our knowledge, none has yet demonstrated the effects of cooking conditions, especially higher than atmospheric boiling point, on the textural and morphological changes of Jasmine rice. Therefore, the objective of this study was to compare the physicochemical, textural and structural properties of cooked KDML 105 rice subjected to different elevated cooking temperatures.

2. Materials and methods

2.1. Rice samples

Polished Thai Jasmine rice, a variety of Khao Dawk Mali (KDML) 105 with low amylose content, used in the experiments, was produced in the northeastern part of Thailand. The milled rice was kept in a cold room at about 10 °C. The average moisture content of raw rice was equal to 11.84 ± 0.08% (wet basis).

2.2. A laboratory-scale pressurized cooker prototype

A laboratory-scale pressurized cooker prototype (Fig. 1) was used to generate various elevated cooking environments; 15 grammes of rice sample were placed in the rice cooker (1). Hot cooking water, at a predetermined temperature, was generated from the pressurized boiler (2) equipped with a 0.85 kW band heater. Appropriate ball valves were opened to allow the hot water to flow into the cooker. By doing so, the designated cooking temperature was immediately reached and sustained by a 1.5 kW band heater with a PID controller. The over pressure in the headspace was adjusted using the pneumatic pump (4). Once rice sample was fully gelatinized; the cooling water from a cooler (3) was introduced into the cooking chamber and the cooked rice sample was safely collected to study the physicochemical properties and structural characteristics.

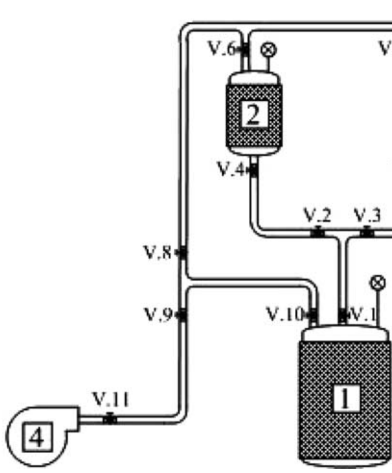

Fig. 1. A schematic diagram of the laboratory-scale pressurized cooker prototype: (1) rice cooker, (2) cooking water chamber, (3) cooling water chamber and (4) pneumatic pump.

2.3. Elevated cooking conditions

Jasmine rice grains were cooked in excess cooking water. The cooking temperatures were 80, 100, 120 and 140 °C at pressures of 0, 0.1, 0.3 and 0.5 MPa (gauge pressure); 15 grammes of milled rice were used and the ratio rice: cooking water added was approximately 10-fold (w/w). The time required to reach gelatinization was determined a priori. The gelatinization assay was defined elsewhere (Leelayuthsoontorn, 2004; Birch & Priestley, 1973). The fully gelatinized rice at 80, 100, 120 and 140 °C was obtained after 22, 14, 8 and 6 min of cooking, respectively. In each cooking process, the cooking solution was decanted and the cooked rice sample was rinsed and cooled with cold water (0–2 °C). The residual water was removed by centrifuging in a basket centrifuge. After cooking, the textural properties and whiteness of cooked rice sample were determined. The structural characteristics of cooked rice were determined.

2.4. Texture measurement

A Texture Analyser (TA-XT2i, Stable Micro System, Surrey, England) was utilized to examine the texture of cooked rice samples using a back extrusion test. A 15 gramme sample of cooked rice was placed inside the test cylinder of 6 cm diameter and pressed with a 100 gramme weight for 30 s before conducting the actual test. During the measurement, cooked rice sample in the cylindrical test cell was compressed by a spherical plate plunger of 35 mm diameter. Pre-test speed, test speed and post-test speed of plunger were set at 1.0, 1.0 and 10 mm/s, respectively. Compression distance was 50% strain. A force–time curve was obtained from the test and the following textural parameters were determined:

hardness – the maximum compressive force during extrusion (N),
stickiness – area under the curve (Ns)

2.5. Whiteness measurement

Whiteness of cooked rice was measured using a colorimeter, JP7100 (Juki Corporation, Tokyu, Japan). Measurement was based on the Hunter system of colour values of L (lightness), a (redness) and b (yellowness) (Lee, Cho, & Rhee, 2001). The measurement was performed in triplicate. The L, a and b values of the white colour standard were 91.77, −0.28 and 0.07, respectively. Furthermore, the whiteness index (WI) was calculated as follows:

$$\mathrm{WI} = 100 - [(100 - L)^2 + a^2 + b^2]^{0.5}$$

2.6. Scanning electron microscopy (SEM)

The morphological change of cooked rice kernels under various elevated cooking conditions was observed using scanning electron microscopy (Jeol JSM-5140, Jeol Ltd., Tokyo, Japan) at 10 kV. The cooked rice kernel was freeze-dried to have a final moisture content lower than 5%. The outer surface on the lateral side of the kernel was observed. The rice kernel was broken along the cross-sectional axis. A location at about 0.1–0.2 mm from the lateral surface was selected and designated as the inner layer endosperm. Samples were attached to a SEM stub using a double-backed cellophane tape. The stub and sample were coated with gold–palladium, examined, and photographed.

2.7. Statistical analysis

All analyses were done in triplicate. An analysis of variance was used to analyze the data and significant differences between the treatment means were compared at a significance level of 95%.

3. Results and discussion

3.1. General

The macroscopic changes of cooked rice as a result of cooking temperatures and pressure levels were described in term of textural and colour alteration, as summarized in Table 1. These cooking results showed, not only the effect of temperature and pressure, but also the effect of boiling environment. The boiling condition was subdued in all treatments except for the treatment at 100 °C and 0 MPa. Due to limitation of thermal properties of water, a few designed treatments (e.g., 120 °C and 0 MPa) were not realizable.

3.2. Textural properties

3.2.1. Hardness

At the same cooking pressure, the hardness of cooked rice decreased significantly as the cooking temperature increased. During cooking, the rice granules absorbed water and swelled to a great extent compared to their original size. The granule expansion caused ruptures and, hence, amylose leaching. Evidence of amylose leaching in the presence of water above the gelatinization temperature is well-documented (Eliasson & Tatham, 2001; Tester & Morrison, 1990; Eliasson & Gudmundsson, 1996). At higher temperatures, amylopectin of lower molecular weight was possibly extracted (Hizukuri, 1996). The amount of starch leaching is a function of temperature and the fine structures of the amylose and amylopectin are related to the texture of cooked rice (Chiang & Yeh, 2002; Ong & Blanshard, 1995). The leaching components were responsible for the reduction of hardness of cooked rice samples.

Table 1
Summary of textural and colour changes of cooked rice samples undergoing various elevated cooking conditions[A]

Temperature (°C)	Pressure (MPa)	Hardness (N)	Stickiness (Ns)	Whiteness
80	0	14.41 ± 0.10[a]	0.22 ± 0.01[b]	69.39 ± 0.13[a]
	0.1	14.76 ± 0.16[a]	0.23 ± 0.02[b]	69.49 ± 0.12[a]
	0.3	15.08 ± 0.16[a]	0.23 ± 0.02[b]	69.22 ± 0.11[a]
	0.5	15.23 ± 0.10[a]	0.22 ± 0.03[b]	69.17 ± 0.17[a]
100	0	11.93 ± 0.14[c]	0.21 ± 0.01[b]	65.04 ± 0.48[c]
	0.1	13.48 ± 0.12[b]	0.25 ± 0.02[b]	66.05 ± 0.28[b]
	0.3	13.92 ± 0.25[b]	0.25 ± 0.02[b]	66.06 ± 0.47[b]
	0.5	13.95 ± 0.27[b]	0.25 ± 0.03[b]	66.26 ± 0.12[b]
120	0.1	11.21 ± 0.10[c]	0.24 ± 0.01[b]	65.70 ± 0.28[b]
	0.3	11.53 ± 0.18[c]	0.24 ± 0.02[b]	65.30 ± 0.14[bc]
	0.5	11.28 ± 0.10[c]	0.25 ± 0.02[b]	65.74 ± 0.37[b]
140	0.3	9.57 ± 0.10[d]	0.39 ± 0.01[a]	64.92 ± 0.12[c]
	0.5	9.49 ± 0.07[d]	0.38 ± 0.01[a]	64.87 ± 0.10[c]

[A] Mean values ± standard deviation ($n = 3$). Different letters within the same column indicate significant difference ($p < 0.05$) using Duncan's multiple range test.

In nearly all cooking temperature experiments, hardness values of cooked rice, at the various cooking pressures were not significantly different, except in the boiling treatment (0 MPa and 100 °C). With this boiling treatment, the hardness of cooked rice was significantly lower than with the other pressures. Perhaps, the boiling condition created excessive attrition between rice grains and caused physical damage to swelling grains. This exterior damage was noticeable by visual examination and characterized by lengthwise fissures on the grain surface. Presumably, these surface cracks facilitated the leaching of amylose and low molecular weight amylopectin; hence, the leaching helped decrease the hardness of cooked rice.

3.2.2. Stickiness

As far as stickiness was concerned, all cooked rice samples at all pressures at temperatures below 120 °C did not show significant differences. However, the stickiness of both pressure treatments at 140 °C differed from the rest of the experiments. The amylose and amylopectin leached out from the inside and were

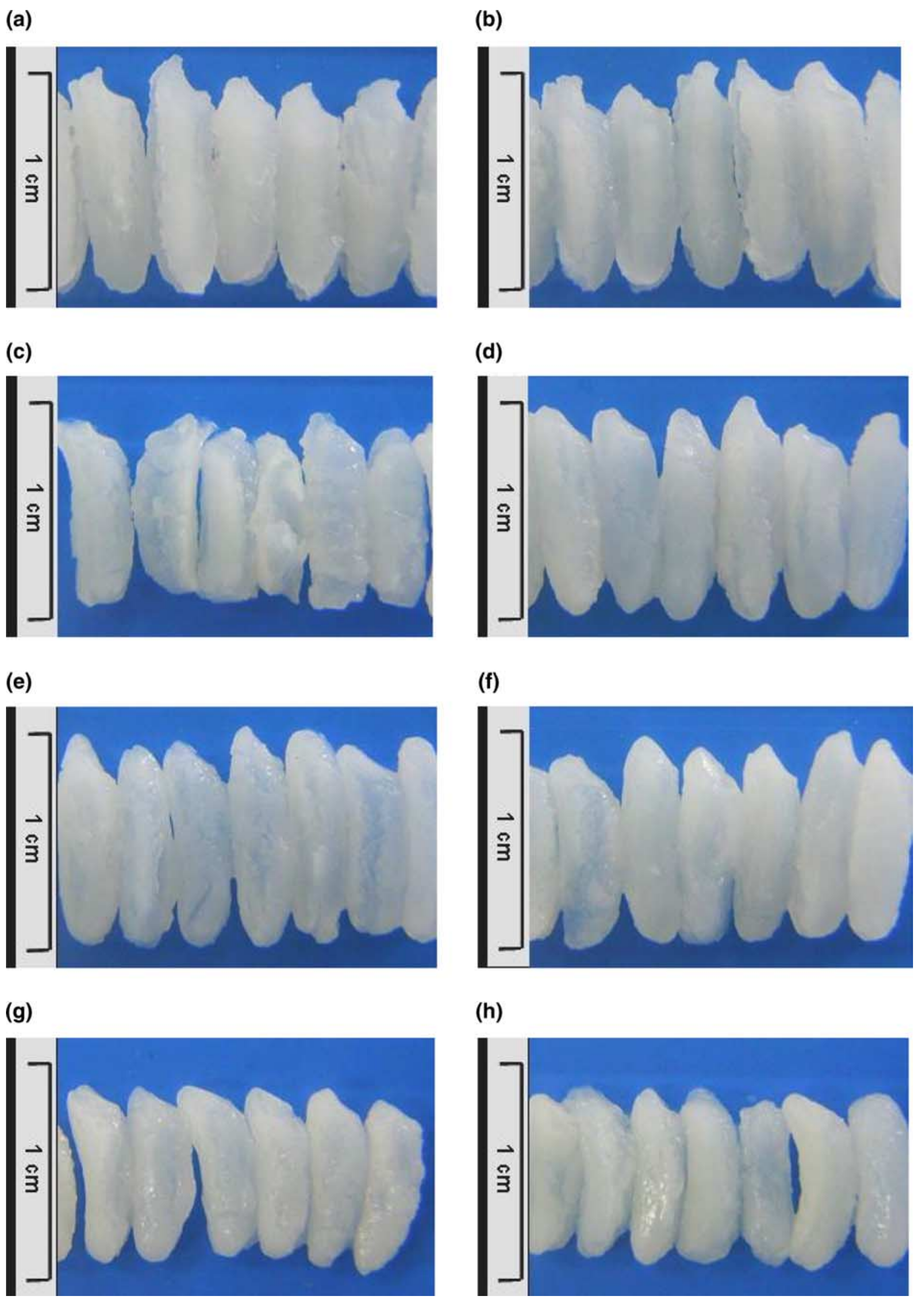

Fig. 2. Apparent quality of cooked rice samples: (a) 80 °C, 0 MPa; (b) 80 °C, 0.5 MPa; (c) 100 °C, 0 MPa; (d) 100 °C, 0.5 MPa; (e) 120 °C, 0.1 MPa; (f) 120 °C, 0.5 MPa; (g) 140 °C, 0.3 MPa and (h) 140 °C, 0.5 MPa.

likely to contribute to the stickiness attribute of cooked rice. Eliasson and Gudmundsson (1996) suggested that the increase of cooked rice stickiness was a function of cooking temperature and derived from the leaking of amylose from the starch granule during gelatinization. A coated film of cooking liquid may form three dimensional networks on the surface of rice grains. By cooking rice in excess water, the cooked rice developed fluffy and non-sticky texture (Desikachar, 1980; Ramesh & Rao, 1996). At lower cooking temperature (e.g., 80, 100 and 120 °C), the amylose leaching was inadequate to generate coated film on rice grains and increase the stickiness. However, higher amylose leakage in the 140 °C treatments may be concentrated enough to form coated film and cause significant increase of stickiness.

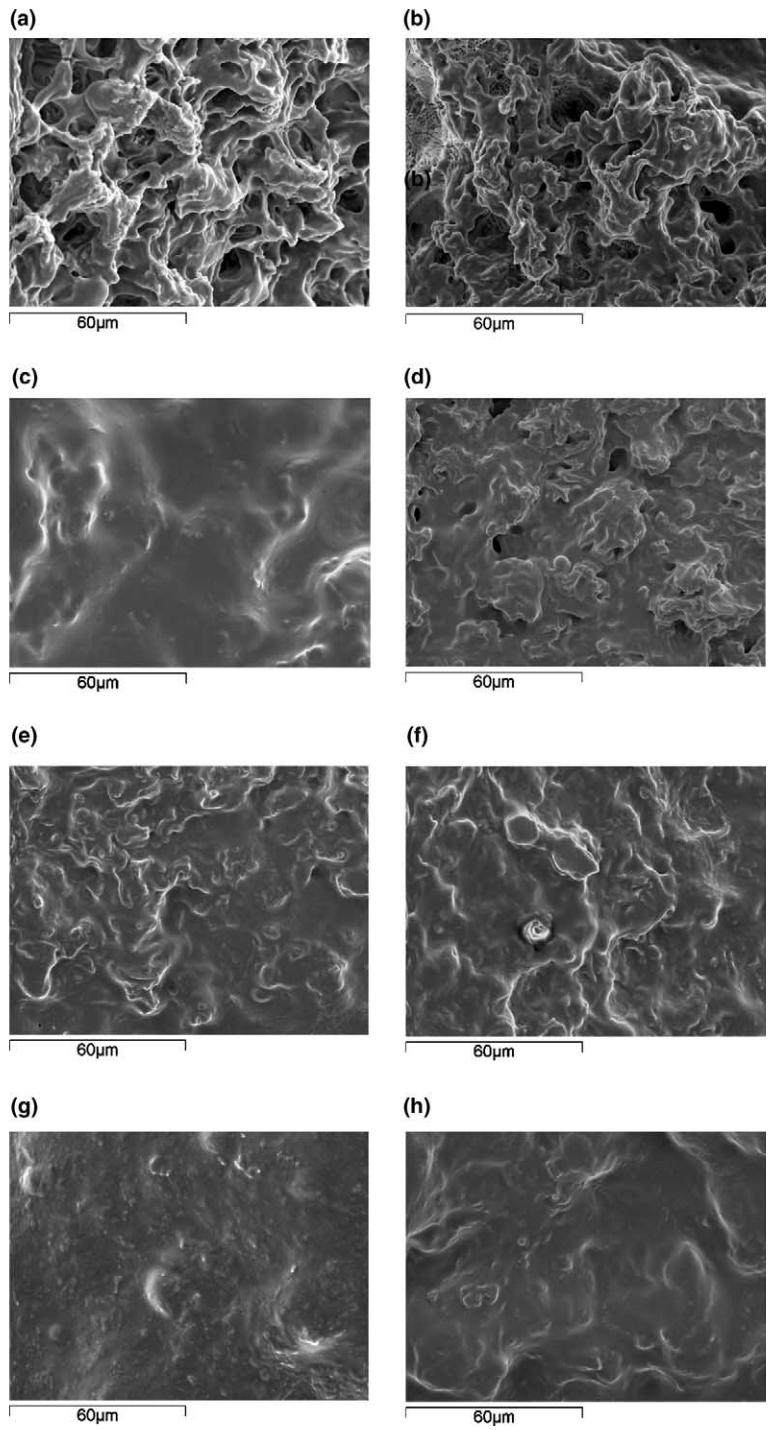

Fig. 3. Scanning electron micrographs of the outer surface of cooked rice: (a) 80 °C, 0 MPa; (b) 80 °C, 0.5 MPa; (c) 100 °C, 0 MPa; (d) 100 °C, 0.5 MPa; (e) 120 °C, 0.1 MPa; (f) 120 °C, 0.5 MPa; (g) 140 °C, 0.3 MPa and (h) 140 °C, 0.5 MPa.

3.3. Whiteness

The degree of whiteness of cooked rice samples decreased as the cooking temperature increased. The cooking temperature was clearly an important factor influencing the degree of whiteness. Higher cooking temperatures caused lower values of whiteness. This result correlated well with the work by (Islam et al., 2004), which reported that the brightness value of parboiled rice decreased with the increase of steaming temperature. The deterioration of whiteness of parboiled rice was more pronounced at higher temperatures. Bhattacharya (1996) observed that extended parboiling darkened the colour of rough rice. The temperature of parboiling

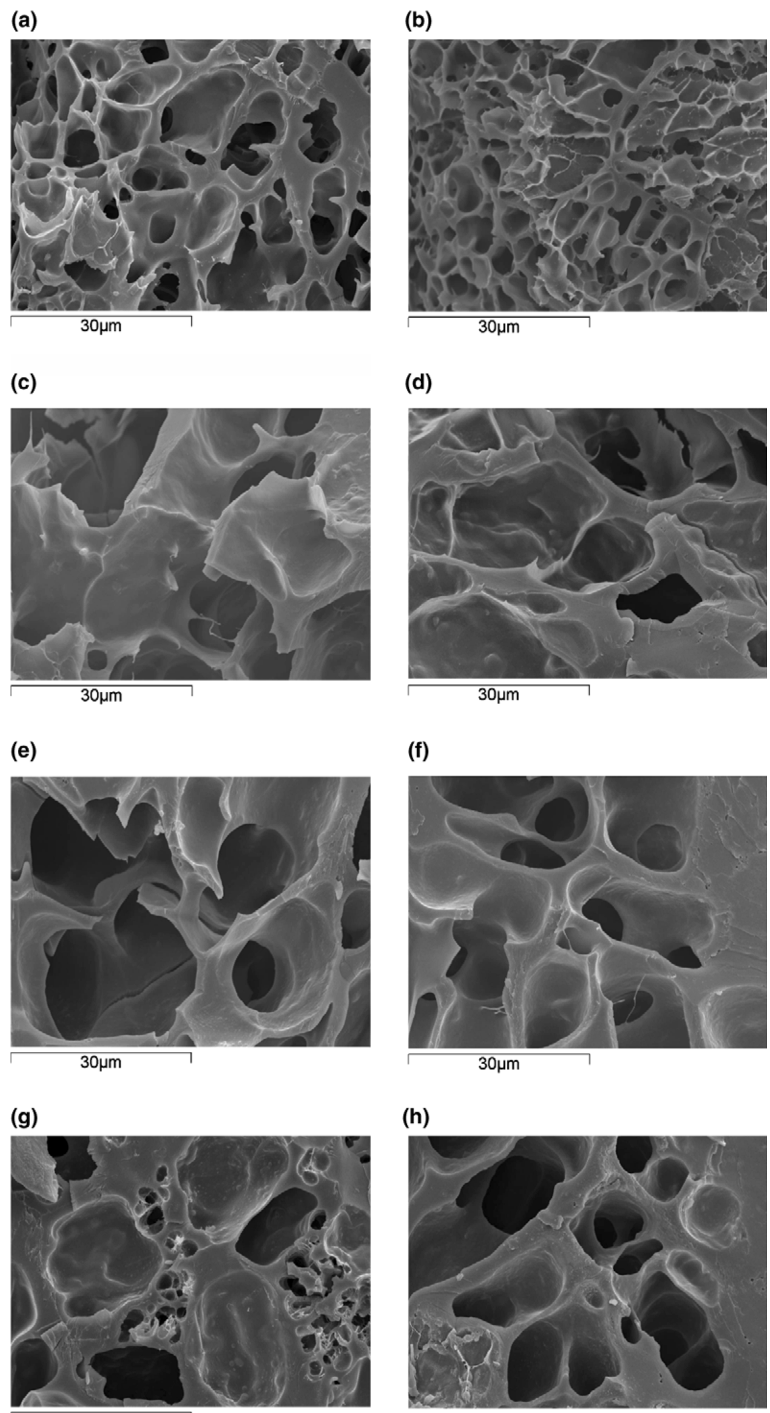

Fig. 4. Scanning electron micrographs of the inner layer of cooked rice: (a) 80 °C, 0 MPa; (b) 80 °C, 0.5 MPa; (c) 100 °C, 0 MPa; (d) 100 °C, 0.5 MPa; (e) 120 °C, 0.1 MPa; (f) 120 °C, 0.5 MPa; (g) 140 °C, 0.3 MPa and (h) 140 °C, 0.5 MPa.

and time of steaming have significant effects on Hunter colour parameters of the end-product. Similar to this experiment, darkening of the cooked rice sample was accompanied by development of a more prominent yellow colour.

By the degree of whiteness, cooked rice samples were dividable into three groups where the degree of whiteness of the cooked rice samples at 100 and 120 °C was equivalent but differentiable from those of the 80 and 140 °C treatments. Also, the colour of cooked rice at 100 °C with boiling was distinguishable from the rest of the 100 °C treatments and similar to the 140 °C treatments.

3.4. Overall physical appearance

Appearance of cooked rice under various cooking conditions is shown in Fig. 2. The photographs of samples obtained after various treatments show that the apparent size of cooked rice samples decreased when the cooking temperature increased. At the same cooking temperature, no significant difference in size was observed between different cooking pressures, except for the boiling condition (Fig. 2(c)). The boiled sample appeared to be excessively swollen and overcooked with axial fissures and gluey outer surface. For the samples at higher temperature (Fig. 2(g) and (h)), the cooked rice kernels were less expansive, curvier and slightly more yellowish in colour.

3.5. Scanning electron microscopy

The higher cooking temperatures produced noticeable changes of microstructure of cooked rice kernels. At low cooking temperature (Fig. 3(a) and (b)), comparable to the normal rice cooking condition, the SEM displayed uneven structure with fine porosity. As temperature increased, the porosity seemed to be gradually dispersed and the surface at high cooking treatment appeared to be smooth and solid. The increase of cooking pressure did not alter the microstructure of the outer layer, except for the boiling treatment (Fig. 3(c)). Boiling destroyed the porous texture and resulted in similar texture of the outer endosperm as that cooked at high temperature.

SEM of the inner layer of rice endosperm showed increase of the pore size and thickness of sponge-like texture as cooking temperature increased (Fig. 4). The changing of cooked rice morphology corresponded to the increase of hardness. The fine porosity at the lower temperature treatment resulted in fluffy and well-expanded cooked rice, whereas the large-pore and thick starch body rendered harder, less-expanded, curly grains. No significant change of inner endosperm texture was observed as a result of higher cooking pressure. Unlike the SEM of the outer surface of cooked rice, the boiling condition did not affect the microstructure of the inner layer endosperm.

4. Conclusion

Elevated cooking conditions affected the external appearance, including colour and texture, as well as the internal structure of cooked rice. The SEM demonstrated the different of microstructures of cooked rice undergoing different cooking conditions. Higher cooking temperature resulted in a larger pore size and bulkier starch matrix in the inner layer endosperm on the microscopic scale. On the macroscopic scale, high temperature produced less-expanded and curvy cooked rice with soft texture and slightly off-colour. Cooking pressure did not affect cooked rice quality. Boiling caused deterioration only of the external appearance (i.e., whiteness) but also softened the texture of cooked rice.

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