Effect of Processing Conditions on Color Change of Brown and Milled Parboiled Rice

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ABSTRACT

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The effects of the soaking and steaming steps in rice parboiling on color changes and the levels of reducing sugars in rice were studied. Brown rice was soaked to different moisture contents (MC, 15, 20, 25, and 30%). The *L*, a*, b** color parameters of the Commission Internationale de L'Eclairage (CIE 1976) indicated that during soaking, red and yellow bran pigments diffused from the bran into the endosperm. The increase in brightness brought about by soaking rice was attributed to migration of rice compounds (e.g., lipids) from the inner to the outer bran layers (rice surface). The levels of reducing sugars in brown and milled soaked rice samples increased with increasing brown rice MC after soaking. The total color difference (ΔE) between parboiled and nonparboiled rice increased with increasing MC after soaking and depended on the intensity of the steaming conditions as reflected in the degree of starch gelatinization. Parboiling affected yellowness more than redness in mildly steamed brown rice and most in intermediately steamed brown rice. Severe steaming of brown rice affected redness more than yellowness. All three parboiling conditions equally affected the yellow color more than the red color in milled rice. Linear regression analyses indicated that parboiling had a larger effect on ΔE of milled parboiled rice than of brown parboiled rice. Furthermore, the linear relationship between the level of gelatinized starch and ΔE of the milled parboiled rice samples showed that both parameters are indicators for the degree of parboiling. Reducing sugars were formed and lost during steaming, suggesting Maillard reactions during steaming.

Parboiled rice constitutes ≈15% of the world's milled rice (Bhattacharya 2004). Parboiling is a three-step hydrothermal process consisting of soaking, heating, and drying. The feedstock for parboiling is paddy or brown rice. As reported by Bhattacharya (2004), a shift to brown rice parboiling was noted during the last 20 years. The use of brown rice has several advantages. It hydrates very fast and has lower weight and volume. Therefore, parboiling is faster and cheaper. Paddy or brown rice is first hydrated to a moisture content of ≈30%. Secondly, the soaked rice is heated to gelatinize the starch. Finally, the heated rice (MC ≈35%) is dried for safe storage and milling (Bhattacharya 2004). White rice is obtained by milling which removes the bran (5–8% of brown rice weight) and the germ (2–3% of brown rice weight) and leaves the starchy endosperm. Parboiling affects the color of milled rice. Milled rice not previously parboiled is white, whereas milled parboiled rice is amber in color. The degree of color change during parboiling is affected by different processing parameters including the soaking water temperature, soaking, and heating duration, and heating and drying temperature (Jayanarayanan 1965; Johnson 1965; Bhattacharya and Subba Rao 1966; Pillaiyar and Mohandoss 1981). The color change of rice during parboiling has been hypothesized to be caused mainly by nonenzymic browning of the Maillard type (Houston et al 1956; Bhattacharya and Subba Rao 1966). Besides nonenzymic browning, husk and bran pigments also appear to contribute to parboiled rice color (Subrahmanyan et al 1938; Bhattacharya and Subba Rao 1966). The contribution of pigments to coloration of parboiled rice is supported by the fact that some nutrients (minerals and vitamins) from the bran diffuse into the kernel and other bran compounds (lipids) leach out during parboiling (Subrahmanyan et al 1938; Ramalingham and Anthoni Raj 1996).

Ali and Bhattacharya (1980) showed that the soaking step of parboiling caused enzymic changes in sugars and amino acids and suggested that such changes contribute to the Maillard reactions and, hence, to rice quality. In earlier studies, Jayanarayanan (1965) showed a negative correlation between amylase activity during soaking and the color of rice, and showed that pH of the soaking medium also affected the color. Color change increases at either side of pH 4.5 and could be partly ascribed to the influence of pH on the enzymic reaction responsible for starch and protein hydrolysis. The levels of reducing sugars and peptides are important in Maillard reactions during heating. Furthermore, pH affects the color of bran pigments. The relative contribution of these two effects on rice color was not determined.

Bhattacharya (1996) found that color development in rice under different parboiling conditions (pressure and steam durations) followed zero-order kinetics. Longer parboiling times gave a linear increase in darkness and yellowness. Lightly colored parboiled rice was obtained using relatively low or high pressures combined with reduced steam duration. Elbert et al (2001) reported that parboiled rice with an acceptable light yellow color was obtained using two-stage drying at <70°C. Besides parboiling conditions, the degree of milling also affects rice color (Johnson 1965; Stermer 1968; Wadsworth 1994). Residual bran tissue results in darker rice.

Thus, parboiling conditions affect color in rice. However, the actual mechanisms of color change need to be elucidated. This study explored mechanisms of color change during the soaking and steaming steps of the parboiling process by determining the color of brown and milled soaked and brown and milled parboiled (soaked and steamed) rice. Because of their importance in Maillard reactions, the effects of soaking and parboiling on the level of reducing sugars were determined. In doing so, the degree of starch gelatinization after steaming was used to classify the steaming conditions as mild, intermediate, and severe.

MATERIALS AND METHODS

Rice Samples

Dehulled brown rice from the long-grain cultivar Puntal (MC 12.0%) was obtained from Masterfoods (Olen, Belgium). The rice was harvested in 2002 and dehulled in Spain. Samples (600 g) were soaked to different moisture contents (MC 15, 20, 25, and 30%) at ambient temperature. The necessary amount of water was added to the brown rice to obtain the desired moisture content by total water absorption. The soaked rice was dried on trays for 48 hr at room temperature. For rice parboiling, the brown rice was soaked to different moisture contents as previously described. The water after soaking brown rice was pH 6.5. Brown soaked rice was then heated by steaming in a cylindrical container at different combinations of time and temperature (4 min, 110°C [1.5 bar]; 44

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TABLE I
Color Parameters L^* (Brightness), a^* (Redness), and b^* (Yellowness) and Total Color Difference (ΔE) of Brown Soaked Rice Kernels

Moisture Content After Soaking (%)	Brown Rice				Milled Rice			
	L^*	a^*	b^*	ΔE	L^*	a^*	b^*	ΔE
Reference[a]	62.0c[b]	5.3ab	24.3b	–	77.1cd	–0.4c	15.7c	–
15	61.8c	5.3ab	24.9a	0.7c	77.5cd	–0.5c	15.7c	0.4d
20	63.3b	5.4a	25.4a	1.7b	77.0d	0.7b	17.7b	2.3c
25	65.3a	5.1b	24.3b	3.3a	78.4a	0.7b	18.2b	3.0b
30	65.1a	5.4ab	23.8c	3.1a	77.7b	1.1a	20.9a	5.5a

[a] Nonsoaked rice.
[b] Values followed by different letters in columns indicate significantly different means at $P < 0.05$.

TABLE II
Color Parameters L^* (Brightness), a^* (Redness), and b^* (Yellowness) of Water-Saturated Butanol Extracts of Flour of Milled Soaked Rice

Moisture Content After Soaking (%)	L^*	a^*	b^*
Reference[a]	83.0a[b]	–1.2c	1.0d
15	77.1b	–1.0b	1.0d
20	75.8c	–1.0b	1.2c
25	73.1d	–0.9a	1.5b
30	72.9d	–0.9a	1.6a

[a] Nonsoaked rice.
[b] Values followed by different letters in columns indicate significantly different means at $P < 0.05$.

TABLE III
Polyphenol Oxidase (PPO) Activity of Brown and Milled Nonparboiled Rice and Brown Rice Fractions

Rice Fraction	PPO Activity (U/mg of sample)
Brown nonparboiled rice	175
F1 (bran)	1,099
F2 (bran and polish)	998
F3 (bran, polish, and outer endosperm)	674
Milled nonparboiled rice	–

min, 110°C; 4 min, 140°C [3.5 bar]; 44 min, 140°C; 24 min, 125°C [2.3 bar]; 24 min, 135°C [3.1 bar]) and dried on trays for 48 hr at room temperature. Milling (60 sec) of the nonsoaked, soaked, and parboiled rice samples was done on a testing mill (TM05C, Satake, Bredbury, UK). The degree of milling (DOM), the weight percentage of rice layers removed by milling, was calculated from the weight of rice before and after milling (Wadsworth 1994). Nonsoaked and soaked rice milling resulted in a DOM of ≈13.0%. DOM of parboiled rice was 8.6–10.7%. The milled rice kernels were ground with a laboratory grinder to pass a 250-μm sieve. Brown, nonparboiled rice was fractionated by abrasive milling, and fractions were collected after 0–7% (F1, bran), 0–9% (F2, bran and polish), 0–18% (F3, bran, polish, and outer endosperm) rice fraction removal.

Chemicals

All chemicals used were of at least analytical grade and obtained from Sigma (Belgium) unless indicated otherwise.

Moisture Content Determination

Moisture content (MC) determination was based on Approved Method 44-15A (AACC International 2000). MC was estimated from the mass loss of ≈1.0 g of accurately weighed rice flour when heating for 90 min at 130°C. Analyses were performed in duplicate.

Color Measurements

A colorimeter (model Colorquest 45/0 LAV, CQ/UNI-1600, HunterLab, Reston, VA) was used for all color determinations (Table I). The instrument was calibrated with a white and black calibration tile. The colorimeter was set to an illuminant condition D_{65} (medium daylight) and a 10° standard observer. Color measurements were made fivefold on samples placed in a clear petri dish. Each sample was covered with a white plate. The color was measured as L^*, a^*, b^* color spaces (CIE 1976). L^* is a measure of the brightness from black (0) to white (100); a^* describes red-green color with positive a^* values indicating redness and negative a^* values indicating greenness; b^* describes yellow-blue color with positive b^* values indicating yellowness and negative b^* values indicating blueness. In our study of the effects of soaking and steaming on rice color, we evaluated color differences. A first possibility is to evaluate the difference in L^*, a^*, and b^* between a sample and a reference. A positive ΔL^* value indicates that the sample is more bright than the reference. Positive Δa^* or positive Δb^* values mean the sample is more red or more yellow than the reference, respectively. In addition, we determined the total color difference (ΔE). Based on ΔL^*, Δa^*, and Δb^* values, ΔE was calculated as (Good 2002)

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad (1)$$

Level of Bran Pigments

Pigments were extracted from soaked rice samples based on Approved Method 14-50 (AACC International 2000). Water-saturated *n*-butanol (6.0 mL) was added to rice flour (1.50 g) to extract carotenoids. After shaking for 2.5 hr, the suspension was filtered (Whatman). The color parameters L^*, a^*, and b^* of filtered water-saturated butanol extracts were determined as described above. Extractions were performed in duplicate (Table II).

Polyphenol Oxidase Activity

To determine polyphenol oxidase (PPO) activity, a modification of a spectrophotometric method (Park et al 1997) was used (Table III). Deionized water (10.0 mL) was added to rice flour (2.00 g) in duplicate. After shaking at 4°C (30 min), the suspension was centrifuged (2,500 × *g*, 10 min). The supernatant, which contained crude PPO extract, was incubated at 37°C (10 min). Immediately after incubation, enzyme extract (100 μL) was added to a solution containing potassium phosphate buffer (2.6 mL, 50 m*M*, pH 6.5), L-dopamine (100 μL, 5 m*M*), L-ascorbic acid (100 μL, 2.1 m*M*), and ethylene diamine tetraacetic acid (100 μL, 0.065 m*M*). The contents were mixed immediately and absorbance of the solution was measured at 265 nm (A_{265}) for 10 min. A correction for substrate autoxidation was made by using deionized water as a control. The change in absorbance was measured and the activity of each sample was calculated as

$$\text{Units/mg of sample} = (\Delta A_{265}/\text{min sample} - \Delta A_{265}/\text{min control})/0.001 \times \text{mg of sample} \qquad (2)$$

One unit is defined as the change of 0.001 absorbance units (AU)/min at A_{265} in a 3.0-mL reaction mix containing L-dopamine and L-ascorbic acid at pH 6.5. The difference between two measurements was < 50 U/mg of sample.

Determination of Reducing Sugars

Dimethyl sulfoxide (90%, v/v, 1.0 mL) was added to rice flour (5.0 mg) and heated (100°C, 10 min) to solubilize starch. The solution was cooled to room temperature and centrifuged (10 min, 10,000 × *g*). Part of the supernatant (250 μL) was diluted with deionized water (750 μL). The method described by Jane and Chen (1992) was used to determine the levels of reducing sugars in the diluted supernatant. Analyses were performed in triplicate. The levels of reducing sugars were expressed on a dry matter basis.

Determination of Gelatinized Starch

Differential scanning calorimetry (DSC) analyses were performed in duplicate (Seiko DSC 120, Kawasaki Kanagawa, Japan). Flour of milled rice (5–7 mg) was accurately weighed into aluminum DSC sample pans and water was added (1:2, w/w, sample dry matter-to-water). After sealing, the sample pan and an empty reference pan were heated from 25 to 140°C at 4°C/min. Calibration was with indium and tin. Enthalpies (ΔH) of the starch gelatinization endotherm were determined with Seiko software and the resulting average enthalpies were expressed in J/g of rice dry matter. Levels of gelatinized starch (Table IV) were estimated from the ΔH of the milled nonparboiled rice flour ($\Delta H_{\text{reference}}$) and the milled parboiled rice flour (ΔH_{sample})

$$\text{Gelatinized starch (\%)} = (1 - \Delta H_{\text{sample}}/\Delta H_{\text{reference}}) \times 100 \qquad (3)$$

Statistical Analyses

To analyze the effects of soaking on the level of reducing sugars and on the color parameters, *t*-test (PROC ANOVA) was used ($P < 0.05$). Pearson's correlation coefficient analyses were determined ($P < 0.05$). Statistical analyses were conducted using the Statistical Analysis System software (v. 8.1, SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Effect of Soaking on Color of Rice

Table I presents the color parameters L^*, a^*, b^* and ΔE of the brown rice kernels soaked to different MC (15, 20, 25 and 30%) and of their corresponding milled rice kernels. Kernel brightness (L^*) of brown soaked rice increased, and redness (a^*) remained constant with increasing MC after soaking. Yellowness (b^*) of the brown nonsoaked rice was lower than that of the rice samples with MC of 15 and 20% after soaking. Soaking to higher MC (25–30%) decreased yellowness. The changes in color parameters L^*, a^* and b^* are also illustrated by the increase in total color difference (ΔE) with increasing MC after soaking (Table I). To gain some insight into the changes in the endosperm during soaking, the color parameters of milled soaked rice kernels were measured (Table I). In contrast to the brown soaked rice kernels, there was no clear effect of soaking on the brightness of the milled soaked rice kernels, and both redness and yellowness of the milled soaked rice kernels increased with increasing brown rice MC after soaking.

The color changes noted in the soaking experiments suggest that some compounds migrate during soaking from the inner layers to the surface, while others, specifically bran compounds, diffuse toward the endosperm as previously described by Subrahmanyan et al (1938) and Ramalingham and Anthoni Raj (1996). The increase in brightness of the brown soaked rice kernels could be explained by diffusion of bran compounds into the endosperm (inward diffusion) and the migration of rice compounds (lipids) from the inner rice layers to the surface (outward migration). Higher MC presumably led to more inward diffusion and outward migration of rice compounds, which explains the increase in brightness with increasing MC after soaking. The fact that the redness of brown rice did not change, while that of the milled rice increased with increasing brown rice MC, could be explained by the diffusion of red pigments from the inner bran layers toward the endosperm.

The increase in yellowness of the milled soaked rice samples could be attributed to the diffusion of yellow bran pigments both from the outer and inner bran layers toward the endosperm because the yellowness of the brown rice kernels decreased with increasing MC. It seems that higher MC after soaking results in more inward diffusion of red and yellow bran compounds. The brown rice kernels soaked to 15 and 20% MC had higher yellow-

TABLE IV
Color Differences ΔL^* (Brightness), Δa^* (Redness), and Δb^* (Yellowness), and Total Color Difference (ΔE)
Between Samples, and Level of Gelatinized Starch of Milled Parboiled Rice[a]

MC (%)[b]	Steaming Conditions	Brown Rice				Milled Rice				Gelatinized Starch (%)
		ΔL^*	Δa^*	Δb^*	ΔE	ΔL^*	Δa^*	Δb^*	ΔE	
15	4 min 110°C	–1.0	0.7	2.0	2.3	2.3	–0.3	0.4	2.4	0.0
20		0.4	0.7	2.2	2.4	1.1	1.0	2.3	2.8	0.0
25		–0.5	0.6	2.4	2.5	0.8	1.3	4.7	4.9	0.0
30		–5.1	2.2	4.6	7.2	–3.0	2.1	8.6	9.4	16.3
15	4 min 140°C	–4.8	2.3	3.6	6.4	1.4	1.0	5.2	5.5	4.1
20		–4.3	2.4	4.2	6.5	–2.5	3.5	8.1	9.2	4.1
25		–7.9	3.2	4.5	9.7	–5.0	4.8	12.1	13.9	17.1
30		–14.4	4.3	4.7	15.8	–9.1	6.1	15.2	18.8	58.5
15	44 min 110°C	–3.1	1.4	3.4	4.8	2.4	0.0	3.2	4.1	9.8
20		–4.4	1.9	4.0	6.2	–0.2	1.3	6.1	6.2	16.3
25		–6.3	2.5	4.4	8.0	–1.2	1.0	8.1	8.2	45.5
30		–10.8	3.9	6.2	13.1	–6.5	2.8	12.3	14.2	60.2
15	24 min 125°C	–5.8	2.7	4.2	7.7	–2.3	2.7	9.3	10.0	14.6
20		–9.5	3.7	4.6	11.2	–4.7	3.9	11.9	13.3	56.9
25		–11.9	4.6	5.5	13.9	–6.9	4.5	13.8	16.1	88.6
30		–15.6	5.8	6.6	17.9	–11.7	6.6	15.6	20.6	100.0
15	24 min 135°C	–8.1	3.0	4.0	9.5	–4.0	3.8	10.6	12.0	37.4
20		–11.7	4.4	4.7	13.4	–7.2	5.1	13.0	15.8	74.8
25		–14.4	4.8	4.5	15.9	–9.7	5.9	15.5	19.2	100.0
30		–18.2	6.0	5.2	19.9	–14.2	8.0	16.7	23.3	100.0
15	44 min 140°C	–18.0	4.4	0.6	18.6	–17.2	9.6	14.2	24.2	73.2
20		–24.4	6.2	–0.9	25.1	–21.7	12.0	15.4	29.2	90.2
25		–25.7	7.1	–0.9	26.7	–24.7	13.4	14.8	31.7	92.7
30		–29.5	7.9	–2.4	30.6	–28.9	14.5	12.7	34.8	94.3

[a] Color differences between brown parboiled rice kernels and brown nonparboiled rice kernels and between that of milled parboiled rice kernels and milled nonparboiled rice kernels, respectively.

[b] Moisture content after soaking (%).

ness than those of the brown nonsoaked rice, which may indicate that mechanisms other than inward diffusion and outward migration of rice compounds occur during soaking. The increase in yellowness may also be due to enzymic discoloration. For example, some oxidation of phenolic compounds by oxido-reductase enzymes such as polyphenol oxidase (PPO) may have occurred during soaking. Determination of PPO activity in brown and milled rice and brown rice fractions confirmed that PPO was present in the bran layers of brown rice (Table III) and that the enzymic activity decreased from the bran layers to the center of brown rice kernels.

In conclusion, yellowness of brown and milled soaked rice is the result of inward diffusion of yellow pigments as well as enzymic activity during soaking. The relative contribution of the two effects apparently depends on the MC after soaking.

Effect of Soaking on Level of Bran Pigments

The levels of pigments from milled soaked brown rice flour were measured to verify whether red and yellow pigments diffuse from the bran layers toward the endosperm and whether the levels of yellow pigments increase due to enzymic discoloration. The pigments were measured by extraction from the flour of milled soaked rice samples with water-saturated butanol. The color parameters L^*, a^*, b^* of the different water-saturated butanol extracts showed that the brightness (L^*) of the different rice extracts decreased as a function of brown rice MC after soaking (Table II). The levels of red (a^*) and yellow (b^*) pigments increased as a function of brown rice MC after soaking. The increase in red pigments in milled soaked rice with increasing MC after soaking confirms the hypothesis that red bran pigments diffuse into the endosperm during brown rice soaking. Inward diffusion of yellow pigments and the action of oxido-reductase enzymes explain the increase in yellowness.

Effect of Soaking on Level of Reducing Sugars

Figure 1 shows that the levels of reducing sugars of brown and milled soaked rice samples increase with increasing brown rice MC after soaking. The increased content of reducing sugars could be attributed to enzymic changes during brown rice soaking. Comparison of the levels of reducing sugars in brown and milled nonsoaked (reference) versus soaked rice showed that the increase in reducing sugars is higher in the bran layers than in the endosperm during brown rice soaking, indicating that most of the biochemical reactions occur in the outer layers, which contain more enzymes than the endosperm (Champagne et al 2004).

Effect of Parboiling on Starch Gelatinization

In our study, the levels of gelatinized starch were used to differentiate between different steaming conditions. Table IV shows the levels of gelatinized starch of the milled parboiled rice samples. Rice with <70% gelatinized starch for all MC levels after soaking was designated as mildly steamed rice. Three different time and temperature combinations (4 min, 110°C, 44 min, 110°C, 4 min, 140°C) corresponded to this criterion. Rice containing >70% of gelatinized starch for all MC after soaking was designated as severely steamed rice. Steaming for 44 min at 140°C corresponded to this group. For intermediately steamed rice, the degree of gelatinization depended on the brown rice MC after soaking: <70% starch was gelatinized with 15% moisture after soaking; >70% starch was gelatinized with 30% moisture after soaking. Rice steamed for 24 min at 125 and 135°C was designated as intermediately steamed rice.

Effect of Parboiling on Color of Rice

Based on the L^*, a^*, b^* color parameters, the total color differences (ΔE) between parboiled (soaked and steamed) and nonparboiled rice kernels were calculated. Table IV shows the effect of parboiling (soaking and steaming) on the color differences ΔL^*, Δa^*, Δb^* and ΔE of the brown and milled parboiled rice kernels at different MC. For both brown and milled rice samples, the total color difference (ΔE) increased with increasing MC after soaking for all steaming conditions. The severity of steaming clearly correlated with the color difference because mild, intermediate, and severe steaming resulted in small, intermediate, and large color differences, respectively. The color differences ΔL^*, Δa^*, and Δb^* between brown parboiled and nonparboiled rice samples depended on the MC after soaking and the steaming conditions. The effect of parboiling on the color differences ΔL^*, Δa^*, and Δb^* increased with increasing MC after soaking. Mild steaming conditions led to greater impact of parboiling on yellow than on red color. At intermediate steaming conditions, the effect on the yellow color was more pronounced than on the red color. Steaming of rice soaked to MC of 25 and 30% at 135°C for 24 min had similar effects on redness and yellowness. Severe steaming had less effect on yellowness than on redness. This was in contrast with the results for milled rice, where the effect of parboiling on yellowness was more pronounced than that on redness for all combinations of MC after soaking and for all steaming conditions. The large effect of parboiling on yellowness of milled rice can probably be attributed to migration of yellow pigments from bran (containing more yellow than red pigments) to the endosperm during soaking and steaming of brown rice, as well as to the color change caused by Maillard reactions. Difference in DOM probably had an effect on color as DOM of the milled parboiled rice samples were 8.6–10.7%. However, color measurements of the nonparboiled rice samples with similar DOM (results not shown) indicated that color changes attributed to the differences in DOM ($\Delta L^* = -1.3$, $\Delta a^* = 0.9$, and $\Delta b^* = 1.6$ for nonparboiled rice with DOM ≈10.5 and ≈9.0%) are relatively small in comparison with the effect of parboiling on color change. In contrast to mild and intermediate steaming, severe steaming decreased Δb^* with increasing MC after soaking for both brown and milled rice. Severe steaming may have transformed yellow pigments into red ones.

The difference in effect of parboiling on brown and milled rice color parameters (ΔL^*, Δa^*, and Δb^*) may indicate that the effect of parboiling on total color difference (ΔE) is different for the bran and the endosperm. This is illustrated in Fig. 2, which shows a linear relation ($r = 0.99$) between the effect of parboiling on ΔE of the brown rice kernels and ΔE of the corresponding milled rice kernels. The slope of the regression line significantly differed from 1.0 ($P < 0.05$), indicating that parboiling has a larger effect on ΔE of the endosperm than on that of the bran. The difference in ΔE could be attributed to the different effects of soaking and steaming on the color parameters of brown and milled rice. Indeed, soaking of brown rice resulted in more bright and less yellow brown rice. When the brown soaked rice was steamed, an opposite effect was observed: there was an increase in darkness, redness, and

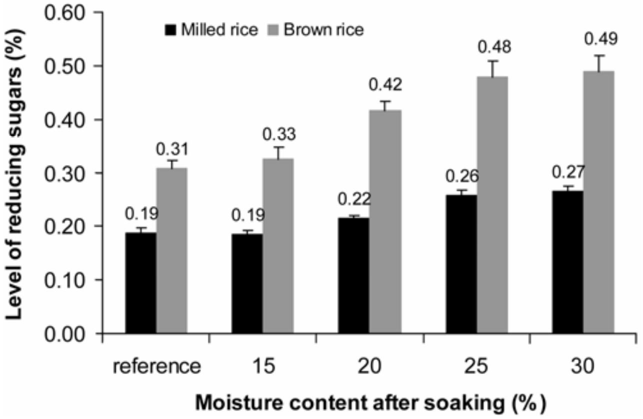

Fig. 1. Effect of soaking on the level of reducing sugars of brown and milled rice.

yellowness. However, in milled rice, both soaking and steaming resulted in an increased redness and yellowness, indicating that steaming intensified the effect of soaking on redness and yellowness of the milled rice.

In earlier studies, the general appearance and measured color of parboiled rice were used to estimate the degree of parboiling (Johnson 1965; Stermer 1968). In the present work, we fitted Δ*E* of the milled parboiled rice as a function of the level of gelatinized starch (Fig. 3). A linear relationship was found between these two parameters ($r = 0.85$), indicating that both Δ*E* and the level of gelatinized starch of milled parboiled rice were indicators for the degree of parboiling. However, it seems that the level of gelatinized starch is a more restricted parameter than Δ*E* for estimating the degree of parboiling. For example, there was no difference in the level of gelatinized starch between rice soaked to 25% MC and steamed 24 min at 135°C and rice soaked to 30% MC and steamed 24 min at 135°C (Table IV). However, there was a difference in Δ*E*. Rice samples soaked to 15, 20, or 25% MC and steamed 4 min at 110°C had no gelatinized starch, while Δ*E* increased as a function of brown rice MC after soaking.

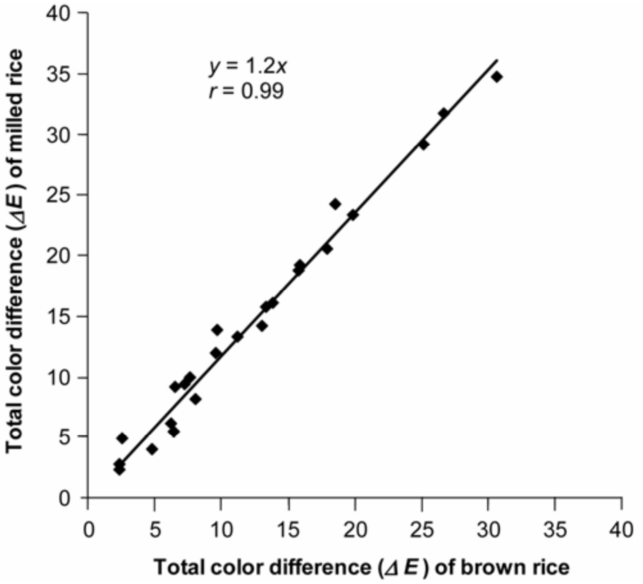

Fig. 2. Effect of mild, intermediate, and severe parboiling on the total color difference (Δ*E*) of brown and milled parboiled rice.

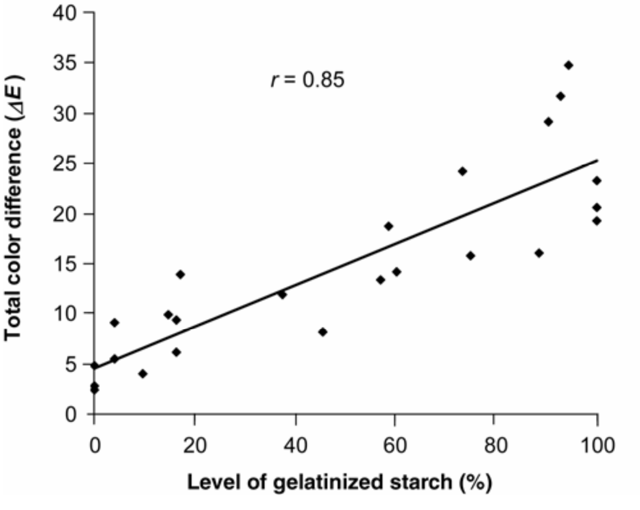

Fig. 3. Total color difference (Δ*E*) of milled parboiled rice as a function of the level of gelatinized starch of milled parboiled rice.

Effect of Parboiling on Level of Reducing Sugars

Figure 4 shows the levels of reducing sugars of milled soaked and milled parboiled (soaked and steamed) rice samples. Although DOM of milled soaked rice was significantly higher than that of milled parboiled rice, it seems that at low MC and for some mild steaming conditions the levels of reducing sugars decreased. Furthermore, it seems that the level of reducing sugars increased at high MC and mild steaming conditions and at all MC and intermediate and severe steaming conditions. This may be explained if one assumes diffusion of reducing sugars from bran layers into the endosperm or thermal degradation of starch during brown rice steaming. The results indicate that steaming induces loss as well as an increase of reducing sugars and that the level of reducing sugars depends on the brown rice MC after soaking and the steaming conditions. Ali and Bhattacharya (1980) demonstrated that the final sugar content in parboiled rice is dynamic because of the increase in reducing sugars due to enzymic conversion of sucrose during soaking and the decrease in reducing sugars during steaming. The decrease during steaming suggests the involvement of reducing sugars in Maillard type reactions.

CONCLUSIONS

The effect of parboiling on rice starch gelatinization, color change, and the level of reducing sugars was studied. Color changes of rice during soaking (by total water absorption) were attributed to inward diffusion of red and yellow pigments and outward migration of bran compounds at the rice surface. Furthermore, some enzymic discoloration may be responsible for the change in yellowness. The increase in the level of reducing sugars in both brown and milled rice samples was attributed to enzymic conversions during soaking. The color measurements of the parboiled rice samples showed that the effect of steaming on color change of rice depends on brown rice MC after soaking as well as on steaming conditions. The decrease in brightness, the increase in redness and yellowness of parboiled rice, and the increase and loss of reducing sugars of milled rice during steaming suggested Maillard type reactions during steaming. Besides Maillard reactions, migration of bran pigments toward the endosperm during steaming was probably a second mechanism explaining the color changes of rice. Further investigation is needed to estimate the relative contribution of Maillard reactions and bran pigments to the color of brown and milled parboiled rice.

Regression analyses demonstrated that the effect of parboiling on Δ*E* is larger for milled rice than for the corresponding brown rice. The correlation between the level of gelatinized starch and Δ*E* of the milled parboiled rice samples led us to conclude that both parameters are indicators for the degree of parboiling.

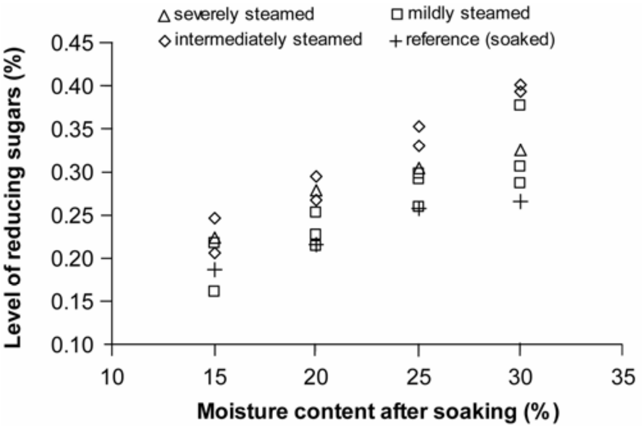

Fig. 4. Effect of mild, intermediate, and severe parboiling on the level of reducing sugars of milled parboiled rice.

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