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Analysis of the tastes of brown rice and milled rice with different milling yields using a taste sensing system

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Abstract

The tastes of brown rice and milled rice with different milling yields were analyzed by a taste sensing system, chemical methods and sensory evaluation. In addition, a study of some physicochemical properties of samples was carried out. Using the taste sensing system with ten sensors made from lipid membranes, both raw and cooked samples of brown rice and milled rice, with different milling yields, were distinguished. A multiple regression analysis, based on taste sensor response electric potential patterns, was conducted to evaluate sensory taste scores and chemical taste components of rice. For both raw and cooked rice, the highest accuracy, shown by coefficient of determination (R^2) and the lowest standard error of the prediction (SEP), were obtained when using a combination of two or three sensors. Hence, differences of tastes between brown rice and milled rice with various milling yields can be evaluated not only by physicochemical measurements but also by the taste sensing system.

Keywords: Brown rice; Milled rice; Milling yield; Taste sensing system; Free sugars; Free amino acids; Physicochemical properties

1. Introduction

Rice is one of the leading food crops in many countries in the world. The palatability of rice is influenced by cultivars, conditions of climate, cultivation, post-harvesting, milling yield and cooking process (Champagne et al., 1997; Champagne, Marshall, & Goynes, 1990). Milling yield affects, not only the eating quality of cooked rice, but also the producer's profit. Some relationships among degree of milling and composition, pasting characteristics and sensory properties of rice have been reported (Champagne et al., 1997; Park, Kim, & Kim, 2001; Perdon, Siebenmorgen, Mauromoustakos, Griffin, & Johnson, 2001; Singh, Singh, Kaur, & Bakshi, 2000). It is well known that milling brings about changes in biological and chemical composition, such as amylase activities, peptidase activities, sugars, fats, amino acids, vitamins and minerals (Barber, 1978; Tajima, Horino, Maeda, & Rok Son, 1992). Sugars such as glucose and sucrose, and amino acids such as glutamic acid and aspartic acid, are the main components (Fukui & Nikuni, 1959; Kasai, Ohishi, Shimada, & Hatae, 2001; Saikusa, Horino, & Mori, 1994; Tajima et al., 1992), that affect the sweetness and umami tastes of rice.

Chemical methods and sensory evaluation have been mainly used for determination of the sweet and the umami tastes. However, the former method is expensive and time consuming. The latter is the basic method, as the human sensory system varies, depending on daily physical and mental conditions. Thus, it is necessary to develop a method that can evaluate many tastes at the same time using only a taste sensor itself.

The taste sensor (electronic tongue) is a sensor, which has been developed on the basis of mechanisms found in biological systems (Toko, 2000a, 2000b). In a gustatory system, substances producing taste are received by the

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biological membrane of gustatory cells in taste buds on the tongue. Information on taste substances is transduced into an electric signal, which is transmitted along the nerve fibre to the brain, where the taste is perceived. Artificial taste sensors, whose transducer is composed of either a lipid membrane (Hayashi, Yamanaka, Toko, & Yamafuji, 1990), chalcogenide glasses (Legin et al., 1997; Vlasov, Legin, Rudnitskaya, D'Amico, & Di Natale, 2000), conducting polymers (Riul, Malmegrim, Fonseca, & Mattoso, 2003), or potentiometric all-solid-state PVC membrane (Gallardo et al., 2003) have been developed to discriminate between several commercial beverages such as, water, pollutants and medicines. A voltammetric electric tongue and a lipid membrane taste sensor have been compared (Ivarsson et al., 2001) and the two sensor systems appear to be equal. Studies on tastes of food, such as Japanese wine ("sake") (Arikawa et al., 1995), coffee (Fukunawa, Toko, Mori, Nakabayashi, & Kanda, 1996), soybean paste (Imamura, Toko, Yanagisawa, & Kume, 1996), and soy sauce (Iiyama, Yahiro, & Toko, 2000), using multi-channel taste sensors, have been reported. It has also been shown that the variations in taste of rice and changes in quality of rice during storage can be distinguished and detected using multi-channel taste sensors (Ohtsubo et al., 2000; Toko, 2000a).

As mentioned above, some studies have been reported on tastes of rice using chemical methods and sensory evaluation, while others have reported quality evaluation of rice using taste sensors, but there is little information about the relationship between the tastes of rice and the response patterns of the sensor. In addition, the milling yield of rice is a very important factor in rice processing, storage, and in the market (Barber, 1978; Champagne et al., 1997; Tajima et al., 1992). The purposes of this study were to investigate how the potential response pattern of the taste sensor can be used as a predictor of cooked rice tastes, elucidate suitable sensors for evaluation of rice tastes and compare the tastes of brown rice and milled rice with different milling yields evaluated by the taste sensor and physicochemical measurements.

2. Materials and methods

2.1. Rice sample

The non-glutinous rice variety Nipponbare, grown in Saitama prefecture, Japan, in 2001, was used. The sample was stored at low temperature (4 °C) before use.

2.2. Milling process

Based on brown rice milling yield (MY) standard (100% MY), the sample was milled to 95%, 90%, 85%, and 80% MY by a Yamamoto polisher (Rice Pal 31, Tendo, Japan).

2.3. Preparation of cooked rice sample

Broken rice was removed. Ten grammes of whole grain was put into the aluminium cup, treated with 16 ml distilled water and soaked for 1 h at room temperature. The sample was cooked and kept warm in an electric rice cooker (RC183, Toshiba Co. Ltd., Japan), then left at room temperature for 2 h. After this procedure the cooked rice was frozen (−20 °C) for one night, then lyophilized for 10 h in a Freeze Drier FD-1 (Tokyo Rikakikai Co., Ltd., Japan). The lyophilized cooked and raw rice grains were milled with a Cyclone sample mill from UDY Corp., Collin, CO. USA and the flours were used for experiments as cooked and raw rice samples. The moisture content of the flour was measured after 1h at 135 °C by an oven-drying method.

2.4. Response of sensors to rice sample

Raw and cooked rice flours (6 g, dry basis) were mixed and homogenized with 150 ml of de-ionized water, then centrifuged for 20 min at 20 °C. The supernatant was used for measurement as a rice sample solution.

The measurements were conducted with a commercial taste sensing system SA 402 (Anritsu, Co. Atsugi, Japan). The detecting sensor part consists of electrodes made of lipid membranes (Table 1), which were purchased from Intelligent Sensor Technology, Inc. Atsugi, Japan. Each lipid membrane was fitted on part of a plastic tube and called a probe, which had a hole so that the inner part of the cylinder was isolated from the outside. The end of the cylinder was sealed with a stopper that helds an Ag/AgCl electrode. The tubes were filled with saturated AgCl/3.3 M KCl solution. The detecting and reference electrodes were immersed in 35ml of rice sample solution by a robot arm. Eight detecting electrodes and two reference electrodes were separated into two groups and connected to a computer recording data for differences in potential between the detecting and the reference electrodes (Fig. 1).

The principle of the taste sensor is the measurement that was made at equilibrium using a voltmeter with currents that approached zero. When the sample and reference solutions were not the same, a difference in potential was observed. As the electric potential of the reference electrode was constant, changes in the cell potential were due to the detecting electrode. For the membrane potentiometric method, the observed potential is dominated by the Donnan potential that develops across the membrane (Ivarsson et al., 2001).

Table 1
Lipids used for the membranes of sensor

No.	Name of sensors	Lipid
1	17017	2-Nitrophenyl octyl ether Phosphoric acid di-*n*-decyl ester
2	13062a	Phosphoric acid di-*n*-decyl ester
3	13066b	Phosphoric acid di-*n*-decyl ester
4	3098	Dioctyl phenyl-phosphonate Hexadecanoic acid
5	22001	Dioctyl phenyl-phosphonate Tetradodecylammoniumbromide
6	5291	2-Nitrophenyl octyl ether Tetradodecylammoniumbromide
7	B199c	Dioctyl phenyl-phosphonate Phosphoric acid di-*n*-hexadecyl ester Tetradodecylammoniumbromide
8	B217d	Dioctyl phenyl-phosphonate Phosphoric acid di-*n*-hexadecyl ester Tetradodecylammoniumbromide
9	B187	2-Nitrophenyl octyl ether Dioctyl phosphate Trioctylmethylammoniumchloride
10	B186	Dioctyl phenyl-phosphonate Dioctyl phosphate Trioctylmethylammoniumchloride

Nos. 1–4 are negative membranes, Nos. 6–7 are positive membranes, and Nos. 7–10 are hybrid membranes of negative and positive membranes; a and b are different amounts of lipid; c and d are different molar ratio of lipids.

Measurement for each sample was carried out after all electric potentials of membranes were stabilized in a standard solution, made of 3 mM potassium chloride and 3 mM potassium tartrate (Arikawa et al., 1995), stabilized for at least one week. The response electric potentials were measured relative to zero response potential to Nipponbare rice 90% MY (standard sample). All measurements were made three rounds by the rotation procedure, which involved thrice of measurement. Since the stopper could hold four probes and one reference electrode, one time of measurement was made by two steps; first, the negative and positive membrane probes and second, the hybrid membrane probes were used. The average values of three measurements were adopted as the response electric potential pattern, and the coefficient of variance was less than 20%.

2.5. Chemical analyses

For measurement of free sugar content; 4 g of raw and/or cooked sample powder were extracted with 15 ml of 50% ethanol, and then centrifuged. The process was repeated twice and the obtained supernatant was reduced to a volume of 1 ml with a Centrifugal Evaporator CVE-2000 (Tokyo Rikakikai Co., Ltd., Japan) then filtered through a 0.45 μm filter (GL chromato-disk 25A, GL Science Co., Ltd., Japan). Twenty microlitre of filtrate were injected, and free sugars were analyzed by high performance liquid chromatography (HPLC). The conditions of HPLC were as follows: controller system (CLS-10AP), refractive index detector (RID-10A), Shimadzu Ltd., Kyoto, Japan; column, Shodex Asahipak NH2P-50 4E (Showa Denko Co., Ltd., Japan), column temperature, 30 °C; solvent, acetonitrile/water (75%/25%); flow rate, 1ml/min. For measurement of free amino acids content, 0.5 g of raw and/or FDC powder was extracted with 5 ml of sulfosalicylic acid (2%) then centrifuged. The supernatant was filtered through a 0.45 μm filter (GL chromato-disk 25A, GL Science Co., Ltd., Japan). Prepared sample solution (10 μl) was analysed by an amino acid analyser (Hitachi 8500, Japan). The total carbohydrate content of samples was measured by the anthrone method (Loewus, 1952). The amylose content of sample was measured by the Juliano method (Juliano, 1971). The nitrogen content of sample was measured using a LECO System (LECO FP-528, LECO Corporation, MI, USA). Supplied EDTA, from LECO Corporation, was used as standard. The protein content of sample was obtained from nitrogen

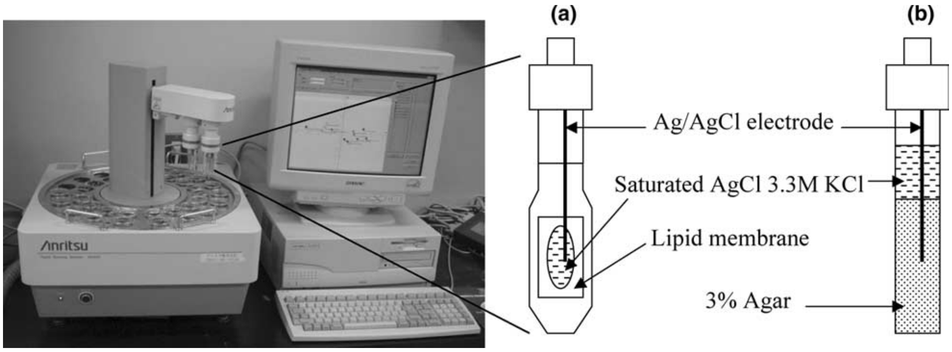

Fig. 1. Taste sensing system (SA 402, Anritsu). (a) Lipid membrane electrode; (b) reference electrode.

by multiplying it by a nitrogen – protein conversion factor of 5.95.

2.6. Sensory evaluation of cooked rice tastes

The sensory evaluation of cooked rice tastes was performed after cooked rice was prepared. Two hundred grams of raw rice grain were soaked with 1.6 volumes of water for 1 h before cooking, and steamed for 15 min. After cooling for 1 h at room temperature, the cooked rice sample (30 g) was placed on a white ceramic plate and presented to panellists. Fifteen panellists were members of the Cereal Science Laboratory, National Food Research Institute, Japan. The panellists were trained in describing, with common words, the taste profiles of cooked rice. Umami taste is produced by monosodium glutamate (MSG), which is found mainly in seaweeds, and sweetness is produced by sucrose, glucose or other sugars. The prepared samples were presented in a random sequence to the panellists, and they were asked to rate the score for each sample using a scale from 1 (weak) to 7 (strong), in comparison with a 90% MY sample that was used as a control (4 points). Four coded samples were served and filtered water was provided for rinsing between samples. Evaluations were conducted at individual desks without talking or exchanging information. The umami score and sweetness score were means of two independent evaluations and the variation from the mean was less than 10%.

2.7. Enzyme activity

α-Amylase and β-amylase activities were determined using the kits of Megazyme International Ireland, Ltd. α-Glucosidase activity was measured according to Imai, Tokutake, Yamaji, and Suzuki (1997), and Iwata et al. (2001). Protease activity was measured by the method of Palmiano and Juliano (1972) with modification. The rice flour (0.5 g) was extracted with sodium phosphate buffer, pH 7.5, containing 0.005 M cysteine for 10 min at room temperature, then centrifuged at 5000 rpm for 15 min at 0 °C. The supernatant was used for assay of protease activity. One millilitre of enzyme solution was incubated with 1.0 ml of 1% bovine albumin (Wako Pure Chemical Com., Kyoto), which was dissolved in water, and 1.0 ml of 0.2 M sodium phosphate buffer, pH 6.5, at 40 °C for 90 min. The reaction was stopped with 1.0 ml of 20% trichloroacetic acid, and the precipitate was aged for 1 h on ice. The mixture was centrifuged at 8000 rpm for 15 min at 4 °C. The supernatant was kept at room temperature for 10 min and the absorbance was read at 280 nm. One unit of protease activity was expressed as the amount of enzyme that produced 0.1 increase in light absorbance of the solution under the conditions of assay.

2.8. Cooking properties

Cooking properties of sample were measured using the method of Batcher, Helmintoller, and Dawson (1956).

2.9. Pasting properties

Pasting properties of raw and cooked rice flours were measured using a RVA (Rapid-Visco-Analayzer, Newport Science Ltd., Australia).

2.10. Physical properties

The physical properties of cooked rice were measured with a Tensipresser (My Boy System, Taketomo Electric Co. Tokyo, Japan) according to the method of Okadome, Toyoshima, and Ohtsubo (1999).

2.11. Statistical analysis

Data obtained were subjected to statistical analysis using SPSS 10.0J software for Windows (SPSS Inc.). Predictive models for tastes of rice, based on potential response patterns of taste sensor, were determined by a stepwise regression procedure. Umami and sweetness scores were obtained from sensory evaluation, and total free sugar and total free amino acids of raw and cooked rice were obtained from chemical analyses, these were used as dependent variables. The potential response patterns of ten sensors for raw and cooked rice solutions were introduced as independent variables or regressors to predict variables from the sensory and chemical evaluations. The best prediction accuracy is judged by the lowest standard error of the prediction (SEP) and highest coefficient of determination (R^2). Significant differences between brown and milled rice were evaluated at the 5% level. Principal component analysis (PCA) was conducted to summarize the effects of MY on response patterns of taste sensors, using the software of Anritsu Co. Ltd., Atsugi, Japan.

3. Results and discussion

3.1. The relationship between response patterns of sensors and values from chemical analyses and sensory evaluation

To determine the relationship between output of sensors and values obtained from chemical analyses and sensory evaluation, multiple regression analysis was performed. Potential response patterns of sensors to raw and cooked rice solutions versus sensory taste scores and/or chemical components were subjected to stepwise multiple regression analyses to investigate how well the rice tastes could be explained by the data from the taste

Table 2
Multiple regression analysis for predicting sensory taste attributes (umami taste and sweetness) and chemical taste components (free amino acids and free sugars) based on the response patterns of sensors to raw and cooked rice samples

Dependent variable	Raw rice			Cooked rice		
	Sensor(s) (independent variable)	R^2	SEP	Sensor(s) (independent variable)	R^2	SEP
Umami	5291 × 3098 × B217	0.997	0.113	13066 × B186 × 3098	0.999	0.062
	529 × 3098	0.990	0.153	13066 × B186	0.959	0.306
	5291	0.967	0.225	13066	0.902	0.389
Sweetness	3098 × 17017	0.984	0.095	B187	0.887	0.205
	3098	0.961	0.121			
Free amino acids	5291 × B186 × 22001	1.000	0.195	13066 × B199 × 13062	1.000	0.092
	5291 × B186	0.999	0.354	13066 × B199	0.999	0.326
	B186	0.996	0.610	13066	0.781	3.851
Free sugars	B217 × B186 × 17017	1.000	0.204	B186 × 22001	0.979	54.888
	B186 × 17017	1.000	3.792	B186	0.693	185.137
	B186	0.994	28.656			

sensors and to find out which sensor is most effective for predicting the tastes of raw and cooked rice. The strongest linear correlations are shown in Table 2. Both raw rice and cooked rice show that umami taste, sweetness, free amino acids and free sugars had the strongest correlations with the combination of potential response patterns of three sensors. The lowest correlation (R^2) and the lowest accuracy (SEP) appeared when only one sensor was used. The results indicated that rice has a mixture of tastes and a specific lipid membrane sensor can not be used alone for evaluation of one taste.

In the case of raw rice, the model using response patterns of positive sensor (5291) in combination with negative sensor (3098) and the hybrid sensor (B217) was most accurate, with $\text{SEP} = 0.113$, $R^2 = 0.997$, for estimation of umami taste, compared with the model using sensor 5291 × 3098, or the model using only sensor 5291, for which SEP and R^2 were 0.153, 0.990 and 0.225, 0.967, respectively. Sweetness showed highest correlation ($R^2 = 0.984$ and $\text{SEP} = 0.095$) with sensor 3098 × 17017. Free amino acid contents of raw rice showed strong correlation with the model using the combination of three types of sensors, positive, negative and hybrid membranes (5291 × B186 × 22001), while free sugar contents showed best correlation when combining the use of the hybrid and the negative membrane sensors, B217 × B186 × 17017. This suggests that the free amino acid content affects the umami tastes of rice, and could be evaluated using three types of sensors. However, the free sugar content, especially, sucrose and glucose which influence the sweetness of rice, could be evaluated by hybrid and negative membrane sensors.

In the case of cooked rice, both umami taste and free amino acid contents had highest correlation with a combination of one hybrid and two negative membrane sensors. The predictive model by those three sensors had the highest R^2 values and the standard error of the estimate SEP that are 0.999; 0.062 and 1.000; 0.092, for umami taste and free amino acid content, respectively. A model based on only one negative sensor, 13066 gave R^2 coefficients of 0.781 and 0.902 which still can be considered high, but the accuracies were 6 times and 5 times lower for umami taste and free amino acid contents, respectively. The model using hybrid sensor B187 could be used for predicting sweetness of cooked rice with R^2 of 0.887 and SEP of 0.205. However, the evaluations of free sugar content, using hybrid and positive membrane sensors or using only hybrid sensor B186, were not considered good model as the SEP were evaluated to be too high. In contrast, the response of sensors to raw rice solutions had high correlation with free sugar content and sweetness.

Previously, several reports have shown that the taste sensor could discriminate between the tastes of amino acids in terms of five basis taste qualities (Toko, 2000a, 2000b), and have distinguished between varieties of soy sauces with high and low concentrations of amino acids (Iiyama et al., 2000). The action of monosodium glutamate (MSG), which produces the umami taste, on the lipid membrane of the taste sensor has also been investigated by Iiyama, Kuga, Ezaki, Hayashi, and Toko (2003). Our present results showed that the negative membrane and hybrid membrane sensors had a strong correlation with umami taste and free amino acid content of cooked rice, as the contents of the amino acid components, especially, glutamic acid and aspartic acid in brown rice, were higher than those in milled rice. These results are promising in terms of the application of the taste sensor as an objective measurement for conventional sensory expressions or chemical analyses in quality evaluation of cooked rice over a wide range.

Fig. 2 shows results of PCA applied to the response electric potential patterns of sensors for cooked rice

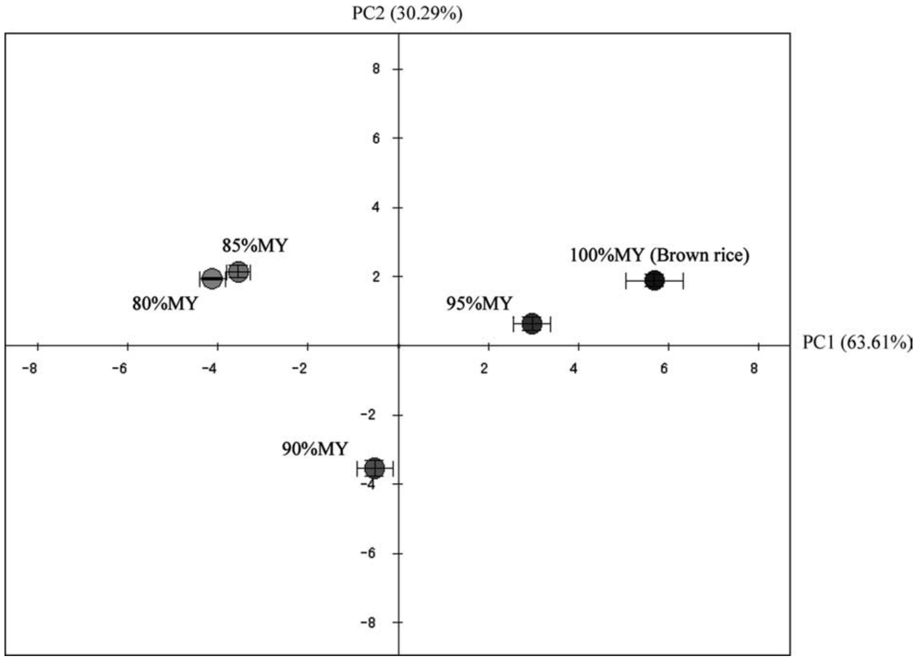

Fig. 2. Applied PCA to the response patterns of sensor (mV) for cooked rice samples (The sensors were used to analyze the following: B187, B186, 5291, 13062, 3098, 22001, B199, B217).

samples. The samples were found to be distributed on the two-dimensional plane of the first and second principal components. The contribution rates of original data to principal components 1 and 2 were 63.61% and 30.29%, respectively. The different milling of cooked rice samples was distinguished by the output patterns of the taste sensor. However, 85% and 80% MY cooked rice samples, which are displayed on the higher-left plane were not clearly distinguished. The research indicated that the taste sensor may be used to distinguish cooked brown rice and milled rice with different milling yields.

3.2. Chemical components and enzyme activity

Sugiyama, Konishi, Terasaki, Hatae, and Shimada (1995) reported that sucrose accounted for 90% of the free sugar and the ratio in the outer layer was more than 60%. In addition, aspartic acid, glutamic acid, serine, and alanine were the main free amino acids and the sum of these four amino acids constituted 56–71% of the total amino acids in the whole kernel and 76–80% in the outer layer. Moreover, the germ contained a greater amount of free amino acids than did any other part of the kernel (Saikusa et al., 1994). Free sugar and free amino acid contents of raw and cooked rice samples are presented in Fig. 3 and Table 3, respectively. Both, raw and cooked, brown rice samples had the highest free sugar and amino acid contents. The free sugar and free amino acid contents were reduced as the milling yield decreased. Among the free sugar contents, the glucose contents of raw and cooked samples were increased with reduction of the milling yield. The glucose content of cooked rice was higher than that of raw rice while the sucrose content was lower. Sucrose is the main free sugar of both raw and cooked samples. In the present study, we also found that aspartic acid and glutamic acid are main free amino acids of both brown and milled rice. The free amino acid components of 85% and 80% MY samples are not so much different from to those of brown rice, with 95%, and 90% MY ($P > 0.05$, Table 3). Thus, free sugars (sucrose and glucose) and free amino

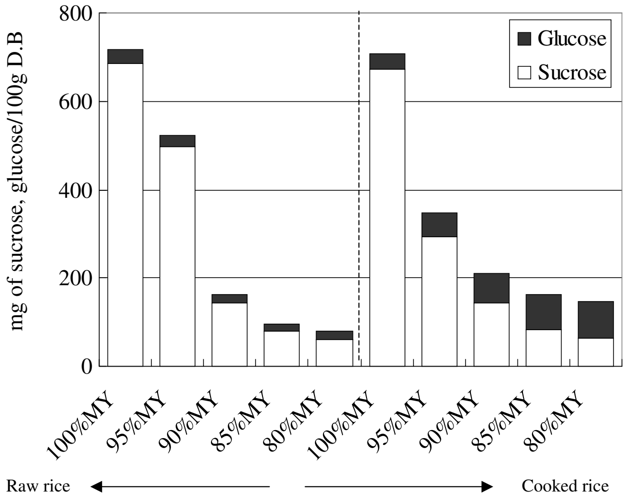

Fig. 3. The glucose and sucrose content of raw and cooked brown rice and milled rice samples with different milling yields. (The values are averages of duplicates; variations from the means were less than 10%).

Table 3
Free amino acid contents of raw and cooked rice samples (mg/100 g powder sample, dry basis)

Components	Raw rice					Cooked rice				
	100%MY	95%MY	90%MY	85%MY	80%MY	100%MY	95%MY	90%MY	85%MY	80%MY
Asp	10.9a	7.60b	4.32bc	3.40c	3.73d	10.3a	7.43b	4.65c	3.94d	3.90d
Thr	0.90a	0.62b	–	–	–	1.00a	0.86b	–	–	–
Ser	2.77a	2.01b	1.10c	1.06c	1.00c	2.85a	2.34b	1.21c	0.97cd	1.05d
Glu	13.1a	9.85b	6.31c	4.86d	5.01d	8.43a	8.09a	6.27b	4.50c	4.38c
Gly	1.16a	0.88b	0.62c	0.57c	0.55c	1.25a	1.16a	0.63b	0.57b	0.61b
Ala	5.22a	3.71b	2.05c	1.95c	1.81c	6.92a	4.23b	2.04c	1.73c	1.82c
Val	2.33a	2.36a	1.87a	2.22a	1.84a	2.85a	2.91a	1.93a	1.79a	1.91a
g-ABA	4.41a	3.22b	0.83c	1.61d	1.39e	7.95a	5.41b	1.21c	1.52cd	1.29d
Lys	1.26	–	–	–	–	0.90a	0.82a	–	–	–
Arg	2.49a	1.29a	–	–	–	2.59a	2.01b	–	–	–
Total amino acids	44.5a	31.5b	17.1c	15.7d	15.33d	45.1a	35.3b	17.9c	15.0d	15.0d

(–) Not detected. Values are averages of duplicates. Variations from the means were less than 5% except for Val, for which it was 10%. The values followed by the same letters in the same row for raw and cooked rice are not significantly different ($P > 0.05$).

acids (aspartic acid and glutamic acid) may be the main components, which affect the tastes of cooked rice, and probably also the response pattern of the sensor.

Shinke, Nishira, and Mugibayashi (1973) found many types of amylases in rice grains. α-Amylase and β-amylase from endosperm tissues of germinating rice seeds were purified by Okamoto and Akazawa (1978). The protease activity was found to reach a maximum on the fifth or sixth day during germination (Palmiano & Juliano, 1972). Awazuhara et al. (2000) assumed that rice containing α-glucosidase, which has a high temperature optimum, is considered to have been selected as good quality rice by Japanese people. In addition, in our study, we found that the α-glucosidase activity of brown rice was lower than that of milled rice while the protease, α- and β-amylase activities of brown rice were highest (Table 4). These activities were reduced with reduction of the milling yield which thus has an impact on the concentration of free sugars and free amino acids of rice.

3.3. Sensory evaluation and physicochemical characteristics

The sensory scores for umami taste and sweetness, cooking properties, and chemical component data are shown in Table 4. Significant differences ($P < 0.05$) of umami taste were observed. The sweet taste of brown rice was highest but not significantly different between the 95%MY sample and the 90%MY sample.

Major differences were clearly observed between milled and brown rice when these had been cooked (Juliano, 1985). Wax or cuticle, located presumably in the seed coat and on the pericarp of brown rice, reduces the rate of water absorption. Desikachar, Raghavendra Rao, and Ananthachar (1965) reported that milling brown rice, to only 2–3% degree of milling, considerably improved water absorption and decreased cooking time. Our results showed that the WUR of brown rice was lowest, and the WUR was increased with the reduction of milling yield (Table 4). The IBV and the solid solution of brown rice were also low while, for others increased with the decrease of milling yield. Both WUR and IBV significantly increased ($P < 0.05$) with decrease of MY. The pH of brown rice was highest but not significantly different ($P > 0.05$) among samples. The total carbohydrate and protein contents were increased with the increase of milling yield. In contrast, the amylose content was reduced when the milling yield increased.

The pasting profiles of raw and cooked rice flours are presented in Table 5. For the raw samples, the peak, minimum and final viscosities of brown rice were the lowest, and these values were increased with the reduction of milling yield. Park et al. (2001) observed that the peak viscosity significantly increased with increased degree of milling. These results were consistent with those of Perdon et al. (2001). In contrast, for the cooked rice samples, the data of brown rice were the highest while, for others they were very low. Even after being cooked, the gelatinization of brown rice was still very high. This may be due to the wax components found in the outer layer coat of brown rice.

The physical properties of cooked rice sample are shown in Table 6. The hardness of cooked brown rice was the highest, whereas the stickiness was lowest in all measurements (LC and HC). In the LC test, the hardness and stickiness had a tendency to be reduced as the milling yield was reduced. However, at 80% MY, the hardness and stickiness were higher than at 85% MY. In LC and HC of single cooked grain, the hardness and stickiness of samples were not increased or decreased regressively. Okadome et al. (1999) pointed out that the differences of stickiness among the cooked rice samples could be detected by the surface adhesion distance (L3) using the LC test. In the present study, we have found that the adhesion distance (L3) increased regressively with the reduction of milling yield, while hardness and

Table 4
Sensory scores, cooking properties, enzyme activities, and chemical components of samples

Sample	Taste sensory scores		Cooking properties				Components			Enzyme activity			
	Umami	Sweetness	WUR (%)	IBV	SS (g)	pH	Amylose (%)	Protein (%)	Total carbohydrate* (mg/g)	α-amylase (CU/g)	β-amylase (BU/g)	α-glucosidase (Units/g)	Protease (Units/g)
100%MY	5.38a	4.50a	206.8a	0.047a	0.0188a	6.70	17.8a	7.45a	25.5a	0.0291a	0.471a	0.230a	2.36a
95%MY	4.44b	4.14b	358.1b	0.241b	0.0891b	6.55	19.2a	7.16b	24.5a	0.0186b	0.224b	0.289b	1.87b
90%MY	4.00c	4.00b	382.6c	0.343c	0.1018c	6.57	19.9b	6.75c	18.9b	0.0056c	0.123c	0.296b	0.85c
85%MY	3.25cd	3.63c	419.8d	0.427d	0.1129d	6.56	21.3b	6.54c	18.3b	0.0043c	0.106d	0.295b	0.61d
80%MY	2.59e	3.12d	494.9e	0.541e	0.1359e	6.61	22.1c	6.57d	16.7b	0.0039c	0.099d	0.295b	0.63d

WUR (%), water up-take ratio; IBV, iodine blue value; SS, solution solid; * expressed as mg of glucose/g powder sample, dry weight basis. CU, Ceralpha Units; BU, Betamyl Units. Values are averages of duplicates. Variations from the means were less than 10% of the means in all cases. The values followed by the same letters in the same column are not significantly different ($P > 0.05$). Value of pH was not significantly different.

Table 5
Pasting properties of raw and cooked rice flours

Samples	Raw rice flour							Cooked rice flour						
	Max. Visc. (RVU)	Min. Visc. (RVU)	Breakdown (RVU)	Final Visc. (RVU)	Setback (RVU)	Peak Time (min)	Pasting Temp (°C)	Max. Visc. (RVU)	Min. Visc. (RVU)	Breakdown (RVU)	Final Visc. (RVU)	Setback (RVU)	Peak Time (min)	Pasting Temp (°C)
100%MY	306.27a	141.93a	164.34a	277.11a	135.18a	6.53a	61.80a	155.25a	135.33a	19.92a	227.00a	91.67a	7.00	88.60a
95%MY	384.70b	172.53b	212.17b	327.95b	155.42b	6.53a	61.90a	75.17b	72.25b	2.92b	117.08b	44.83b	7.00	88.60a
90%MY	455.18c	207.83c	247.35c	357.59cd	149.76ab	6.60b	66.45b	70.58c	58.00c	12.58c	92.50c	34.50c	7.00	80.20b
85%MY	472.41d	207.47c	264.94d	361.57c	154.10b	6.67c	68.65c	71.33c	68.42d	2.92b	102.00d	33.58d	7.00	88.60a
80%MY	477.11e	225.06d	252.05cd	367.71d	142.65a	6.73d	62.55d	69.83c	69.58d	0.25d	109.17e	39.58e	7.00	70.55c

Values are averages of duplicates. Variations from the means were less than 5% of the means in all cases. The values followed by the same letters in the same column are not significantly different ($P > 0.05$). Value of peak time of cooked rice flour was not significantly different.

Table 6
Physical properties of cooked rice grain

Sample	Low compression test (25%)			High compression test (90%)			
	Hardness (H1; 10^4 dyn)	Stickiness (−H1; 10^3 dyn)	Balance degree (−H1/H1)	Adhesion distance (L3, mm)	Hardness (H2; 10^6 dyn)	Stickiness (−H2; 10^5 dyn)	Balance degree (−H2/H2)	Adhesion distance (L6, mm)
100%MY	21.96 ± 13.96a	3.68 ± 3.65a	0.02 ± 3.10a	0.28 ± 0.17a	2.75 ± 0.53a	1.28 ± 0.058a	0.049 ± 0.028a	0.73 ± 0.79a
95%MY	8.47 ± 1.77b	22.43 ± 5.39b	0.27 ± 0.05b	1.21 ± 0.44b	2.33 ± 0.23b	4.71 ± 0.063b	0.205 ± 0.042b	2.70 ± 0.75b
90%MY	8.84 ± 1.48b	27.34 ± 5.87bc	0.31 ± 0.06b	1.29 ± 0.30b	2.37 ± 0.30b	4.84 ± 0.041b	0.208 ± 0.036b	2.16 ± 0.71bc
85%MY	8.04 ± 2.91b	24.42 ± 9.81bc	0.30 ± 0.00b	1.42 ± 0.48b	2.34 ± 0.36b	4.89 ± 0.066b	0.212 ± 0.034b	2.28 ± 0.65c
80%MY	5.64 ± 2.23b	17.34 ± 8.30c	0.31 ± 0.08b	1.47 ± 0.51b	2.29 ± 0.40b	4.51 ± 0.071b	0.198 ± 0.026b	2.49 ± 0.71c

Values are averages of 20 individual grains measurements ± SD. The values followed by the same letters in the same column are not significantly different ($P > 0.05$).

stickiness were not significantly different among milled rice samples.

4. Conclusions

The present investigation showed that brown and milled rice with different milling yields could be distinguished by taste sensor in both raw and cooked flour forms. The taste sensor with lipid membranes could be used for evaluation of rice tastes. The sensors with negative and hybrid membranes are most suitable for prediction of rice umami taste. It is possible to determine the milling yield and tastes of brown rice and milled rice using the taste sensor. The brown rice has higher free sugar, amino acid contents, peak viscosity, amylase activity, protease activity, protein content, and total carbohydrate content, and less amylose content, WUR, α-glucosidase activity and stickiness than does the milled rice. The taste components, WUR, and peak viscosity were reduced with the reduction of the milling yield. Differences of brown rice and milled rice with different MY can be determined not only by physicochemical methods but also by taste sensor.

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References

Arikawa, Y., Toko, K., Ikezaki, H., Shinha, Y., Ito, T., Oguri, I., & Baba, S. (1995). Analysis of sake taste using multi-electrode taste sensor. *Sensors and Materials, 7*(4), 261–270.

Awazuhara, M., Nakagawa, A., Yamaguchi, J., Fujiwara, T., Hayashi, H., Hatae, K., Chino, M., & Shimada, A. (2000). Distribution and characterization of enzymes causing starch degradation in rice (*Oryza sativa* Cv. Kohihikari). *Journal of Agriculture and Food Chemistry, 48*, 245–252.

Barber, S. (1978). In D. F. Houston (Ed.), *Rice: Chemistry and technology* (pp. 215–263). USA: The America Association of Cereal Chemists, Inc..

Batcher, O. M., Helmintoller, K. F., & Dawson, E. H (1956). *Rice Journal, 59*, 4–8.

Champagne, E. T., Bett, K. L., Vinyard, B. T., Wedd, B. D., McClung, A. M., Barton, F. E., Lyon, B. G., Moldenhauer, K., Linscombe, S., & Kohlwey, D. (1997). Effects of drying conditions, final moisture content and degree of milling on rice flavor. *Cereal Chemistry, 74*, 566–570.

Champagne, E. T., Marshall, W. E., & Goynes, W. R. (1990). Effects of degree of milling and lipid removal on starch gelatinization in the brown rice kernel. *Cereal Chemistry, 67*, 570–574.

Desikachar, H. S. R., Raghavendra Rao, S. N., & Ananthachar, T. K. (1965). Effect of degree of milling on water absorption of rice during cooking. *Journal of Food Science and Technology, 2*, 110.

Fukui, T., & Nikuni, Z. (1959). Changes in sugar contents during the germination of rice seed. Application of the ion exchange resin chromatography. *Nippon Nogei Kagaku Kaishi, 33*, 72–78 (in Japanese).

Fukunawa, T., Toko, K., Mori, S., Nakabayashi, N., & Kanda, M. (1996). Quantification of taste of coffee using sensor with global selectivity. *Sensors and Materials, 8*(1), 47–56.

Gallardo, J., Alegret, S., Munoz, R., De-Roman, M., Leija, L., Hernandez, P. R., & Del Valle, M. (2003). An electronic tongue using potentiometric all-solid-state PVC membrane sensors for simultaneous quantification of ammonium and potassium ions in water. *Analytical and Bioanalytical Chemistry, 377*(2), 248–256.

Hayashi, K., Yamanaka, M., Toko, K., & Yamafuji, K. (1990). Multichannel taste sensor using lipid membranes. *Sensor and Actuators B, 2*, 205–213.

Iiyama, S., Kuga, H., Ezaki, S., Hayashi, K., & Toko, K. (2003). Peculiar change in membrane potential of taste sensor caused by umami substances. *Sensors and Actuators, 91*(1–3), 191–194.

Iiyama, S., Yahiro, M., & Toko, K. (2000). Measurements of soy sauce using taste sensor. *Sensor and Actuators B, 66*, 205–206.

Imai, Y., Tokutake, S., Yamaji, N., & Suzuki, M. (1997). An improved method for measuring of α activity in rice koji. *Journal of Brewing Society Japan, 92*(4), 296–302 (in Japanese).

Imamura, T., Toko, K., Yanagisawa, S., & Kume, T. (1996). Monitoring of fermentation process of miso (soybean taste) using multichannel taste sensor. *Sensor and Actuators B, 37*, 179–185.

Ivarsson, P., Kikkawa, Y., Winquist, F., Krantz-Rulcker, C., Hojer, N. E., Hayashi, K., Toko, K., & Lundstrom, I. (2001). Comparison of a voltammetric electronic tongue and a lipid membrane taste sensor. *Analytica Chimica Acta, 449*, 59–68.

Iwata, H., Iwase, S., Takahama, K., Matsura, H., Itani, T., & Aramaki, I. (2001). Relationship between α glucosidase activity and physical and chemical properties of rice. *Nippon Shokuhin Kagaku Kaishi, 48*(7), 482–490.

Juliano, B. O. (1971). A simplified assay for milled-rice amylose. *Cereal Science Today, 12*, 334–360.

Juliano, B. O. (1985). *Rice: Chemistry and technology* (2nd ed., pp. 36, 423–435). USA: The America Association of Cereal Chemists, Inc..

Kasai, M., Ohishi, K., Shimada, A., & Hatae, K. (2001). Taste properties of cooked rice based on an analysis of the cooked rice extracts. *Journal of Cookery Japan, 34*(4), 373–379.

Legin, A., Rudnitskaya, A., Vlasov, Y., Di Natale, C., Davide, F., & D'Amico, A. (1997). Tasting of beverages using an electronic tongue. *Sensor and Actuators (B), 44*, 291–296.

Loewus, F. A. (1952). Improvement in anthrone method for determination of carbohydrates. *Analytical Chemistry, 24*, 219.

Ohtsubo, K., Ikezaki, H., Taniguchi, A., Okadome, H., Toyoshima, H. & Inbe, T. (2000). Investigation on palatability assay of rice grains by the taste sensor system. *Technical Report of IEICE* (pp. 25–29). OME2000-62 (in Japanese).

Okadome, H., Toyoshima, H., & Ohtsubo, K. (1999). Multiple measurements of physical properties of individual cooked rice grains with a single apparatus. *Cereal Chemistry, 76*(6), 855–860.

Okamoto, K., & Akazawa, T. (1978). Purification of α- and β-amylase from endosperm tissues of germinating rice seeds. *Agricultural and Biological Chemistry, 42*(7), 1379–1384.

Palmiano, E. P., & Juliano, B. O. (1972). Biochemical changes in the rice grain during germination. *Plant Physiology, 49*, 751–756.

Park, J. K., Kim, S. S., & Kim, O. K. (2001). Effect of milling ratio on sensory properties of cooked rice and on physicochemical properties of milled and cooked rice. *Cereal Chemistry, 78*(2), 151–156.

Perdon, A. A., Siebenmorgen, T. J., Mauromoustakos, A., Griffin, V. K., & Johnson, E. R. (2001). Degree of milling effects on rice pasting properties. *Cereal Chemistry, 78*(2), 205–209.

Riul, A., Malmegrim, R. R., Fonseca, F. J., & Mattoso, H. (2003). An artificial taste sensor based on conducting polymers. *Biosensors and Bioelectronics, 18*(11), 1365–1369.

Saikusa, T., Horino, T., & Mori, Y. (1994). Distribution of free amino acids in the rice kernel and kernel fractions and the effect of water soaking on the distribution. *Journal of Agriculture and Food Chemistry, 42*, 1122–1125.

Shinke, R., Nishira, H., & Mugibayashi, N. (1973). Types of amylases in rice grains. *Agricultural and Biological Chemistry, 37*(10), 2437–2438.

Singh, N., Singh, H., Kaur, K., & Bakshi, M. S. (2000). Relationship between the degree of milling, ash distribution pattern and conductivity in brown rice. *Food Chemistry, 69*, 147–151.

Sugiyama, S., Konishi, M., Terasaki, D., Hatae, K., & Shimada, A. (1995). Determination of the chemical components and distribution in the milled rice kernel. *Nippon Shokuhin Kagaku Kogaku Kaishi, 42*(6), 401–409.

Tajima, M., Horino, T., Maeda, M., & Rok Son, J. (1992). Maltooligosaccharides extracted from outer-layer of rice grain. *Nippon Shokuhin Kogyo Gakkaishi, 39*(10), 857–861.

Toko, K. (2000a). *Biomimetic sensor technology* (pp. 164–165). Cambridge University Press.

Toko, K. (2000b). Taste sensor. *Sensors and Actuators B, 64*, 205–215.

Vlasov, Y. G., Legin, A. V, Rudnitskaya, A. M., D'Amico, A., & Di Natale, C. (2000). "Electronic tongue" – new analytical tool for liquid analysis on the basis of non-specific sensors and methods of pattern recognition. *Sensors and Actuators (B), 65*, 235–236.