Effect of Milling Ratio on Sensory Properties of Cooked Rice and on Physicochemical Properties of Milled and Cooked Rice

Jung Kwang Park,[1] Sang Sook Kim,[2] and Kwang Ok Kim[1,3]

Cereal Chem. 78(2):151–156

ABSTRACT

Quantitative descriptive analysis of cooked rice was performed to investigate the effect of milling ratios (≈8.0–14.0%, based on brown rice) on sensory characteristics of cooked rice, in relation to physicochemical characteristics of milled rice and cooked rice. The proximate composition of uncooked rice decreased with increased milling while whiteness increased. The initial pasting temperature of rice flour decreased with increased milling while peak, breakdown, and setback viscosities increased. The instrumental texture profile of cooked rice revealed that hardness and chewiness decreased with increased milling while adhesiveness increased. A trained panel found that color, intactness of grains, puffed corn flavor, raw rice flavor, wet cardboard flavor, hay-like flavor, and bitter taste were lower while glossiness, plumpness, and sweet taste were higher with increased milling. Degree of agglomeration, adhesiveness, cohesiveness of mass, inner moisture, and toothpacking of cooked rice increased while hardness and chewiness decreased with increased milling. Sensory analysis of cooked rice was more discriminating than instrumental texture profile analysis in terms of hardness, adhesiveness, and cohesiveness. There were high negative correlations between descriptive attributes of sweet taste, degree of agglomeration, adhesiveness, cohesiveness of mass, and moisture (r = –0.94 to –0.87), protein (r = –0.96 to –0.83), and fat contents (r = –0.91 to –0.85). Instrumental hardness showed high correlation with sensory hardness (r = 0.80).

Rice is a staple food in many countries, including Korea. Eating quality of rice is of a great concern to consumers and rice breeders and is influenced by the species, conditions of cultivation and postharvesting, degree of milling, and cooking methods (Morrison and Azudin 1987; Chrastil 1989). Degree of milling affects not only the the eating quality of cooked rice but also the profit for the rice farmers. The eating quality of brown rice was reported as inferior to that of milled rice (Juliano 1985a). However, increased milling of rice does not always result in a higher eating quality, according to Kwon and Jeon (1991). They reported that increased milling did not improve the sensory quality of cooked rice after a long period of grain storage. The optimum degree of rice milling should be determined on the basis of eating quality of rice and of the profits for rice farmers. To establish the optimum degree of milling, a thorough investigation should be made of the effect of milling ratio on the sensory characteristics of cooked rice.

Higher water binding capacity, swelling power, solubility, and peak viscosity have been observed with higher degree of milling (Champagne et al 1990; Kim and Jeon 1996). Decreased gelatinization onset temperature and peak temperature (Champagne et al 1990; Marshall 1992) and reduced cooking time of rice (Desikachar 1965) have also been found with increased milling. Champagne et al (1997) studied the effects of degree of milling on sensory flavor of cooked rice and found that flavor intensities of cooked rice prepared with a higher degree of milling were dependent on variety or location and moisture content. Recently, Meullenet et al (1999) reported the effects of rough rice drying and storage conditions on the descriptive profile of cooked rice. They found a decrease in the firmness of the cooked kernels with higher drying temperatures, and lower starchy, clumpiness, gluiness, overall sensory impression, and cohesiveness of mass scores with longer storage times. However, the effect of degree of rice milling on sensory attributes of cooked rice, other than flavor, still remains to be studied. The objectives of this study were to investigate the effects of milling ratio (8.0, 9.5, 11.0, 12.5, and 14.0%, based on brown rice) on physicochemical properties of milled and cooked rice and sensory characteristics of cooked rice. Correlation coefficients were also obtained between physicochemical parameters and sensory attributes of cooked rice.

[1] Dept. Foods and Nutrition, Ewha Womans University, Seoul 120-750, Korea.
[2] Rice Research Group, Korea Food Research Institute, Seongnam 463-420, Korea.
[3] Corresponding author. Phone/Fax: 82-2-3277-3095; E-mail: kokim@mm.ewha.ac.kr

Publication no. C-2001-0207-03R.

MATERIALS AND METHODS

Rice Samples

Paddy rice (cv. Dong-Jin, short grain), purchased through Irri Agricultural Cooperation (Chulla Province, Korea), was dehulled using a Satake rice machine (Type THU, Satake Engineering Co., Tokyo). After dehulling, the brown rice was milled using a testing rice mill (VP-31T, Fujihira Factory, Tenzusi, Japan) to various degrees of milling (8.0, 9.5, 11.0, 12.5, and 14%, based on brown rice). The degree of milling was determined using the equation: Degree of milling = (1 – [weight (g) of milled rice/weight (g) of brown rice]) × 100. Broken kernels were removed using a Satake test rice grader (Type TRG, Satake) with cylinder number 4.75 by the method suggested in the manual for measuring percentage of broken kernels. The milled rice samples were stored at 4°C in polyethylene bags for a maximum of one month.

Physicochemical Characteristics of Milled Rice

Moisture content of milled rice was measured by a single kernel moisture tester (CTR-800E, Shizuoka Seiki, Shizuoka, Japan) and protein (N × 5.95), fat, and ash contents (dry weight basis) were determined according to AOAC methods (AOAC 1995). The whiteness of rice was determined by a digital whiteness meter (C-300-3, Kett Electric Lab, Tokyo).

Rice was milled to flour using a Cyclotec sample mill (1093, Tecator, Co. Ltd., Hogenas, Sweden) and 8% (dwb, w/w) rice flour dispersion was used to measure pasting characteristics with a Brabender Viscograph (PT 100, Brabender Co., Duisburg, Germany). The temperature was raised from 30 to 95°C, held at 95°C for 15 min, then cooled to 50°C at a rate of 1.5°C/min as described by Medcalf and Gilles (1965). Pasting characteristics were determined by measuring peak viscosity, viscosity at 95°C, viscosity at 95°C after holding for 15 min, viscosity at 50°C, consistency, breakdown, and setback viscosity. Peak viscosity was the maximum viscosity in the amylogram; consistency was the viscosity difference between at 50 and at 95°C after holding for 15 min; and breakdown was the difference between viscosity at 95°C after holding 15 min and peak viscosity. Setback viscosity was calculated by subtracting peak viscosity from viscosity at 50°C.

Preparation of Cooked Rice

Cooked rice samples for both instrumental and sensory analysis were prepared. Rice (500 g, 14% moisture basis) was rinsed with water five times. Tap water passed through a water purifier (Supercape, Dalton, Fairey Industrial Ceramics Ltd., London) was added to the rice to give a weight ratio of 1.45:1, after which the rice was soaked for 30 min at room temperature (22 ± 2°C), then cooked in an automatic rice cooker (NZF-076T, Samsung Co., Seoul, Korea). Twenty minutes after the cooker shifted from cook to warm setting, the cooked rice within 1 cm of the top, bottom, and side of the inner pan in the rice cooker was discarded and the middle portion was transferred to a bowl (23.5 cm diameter × 13.5 cm depth). Cooked rice in a bowl was stirred gently five times with a fork (35 cm length) using an up and down motion, then held for 5 min at room temperature. Stirring and holding procedures of cooked rice were repeated twice. The cooked rice was then cooled to ≈28°C (≈30 min) and portioned for sensory evaluation and textural measurements.

Physicochemical Characteristics of Cooked Rice

Moisture content of cooked rice was determined at 130°C in a drying oven (model 0445, Dongyang Science Co., Seoul, Korea) for 24 hr, and the amount of water evaporated during cooking was determined using the equation $We = (R + W) - Rc$, where We is the amount of water evaporated (g), R is the weight of milled rice (g), W is the weight of water added, and Rc is the weight of cooked rice.

Texture profile analysis (TPA) of cooked rice was performed using a texture analyzer (TA-XT2, Texture Technologies Corp., Scarsdale, NY) with a 5-kg load cell using a two-cycle compression (Suzuki 1979). Cooked rice (12 g) was molded into a block using a cylindrical container (2.5 cm diameter × 1.0 cm depth) for testing. The cooked rice sample was compressed to 60% with a rod-type probe (2.5 cm diameter × 15 cm length) at a speed of 1.7 mm/sec. Hardness, adhesiveness, springiness, cohesiveness, chewiness, and resilience were determined from the two-cycle curves using Texture Export for Window (Stable Micro Systems, Godalming, UK). All physicochemical analyses were repeated three times per replicate.

Descriptive Analysis of Cooked Rice

Out of 40 potential panelists, 15 were screened using 24 triangle tests based on a 60% correct answer. Triangle tests included taste solutions and a series of rice samples varying in soaking and cooking times. Panelists were trained for 1.5 hr/day, three times per week for three months. Training included presentation of rice samples; development of descriptive terminology for appearance, flavor, and textural characteristics of cooked rice; and establishment of references (Table I) for each sensory attribute. Ten panelists were selected (Cross et al 1978) and were further trained for two months. Twenty-three descriptive attributes (Table II) were finally selected for the descriptive analysis of cooked rice. The consensus on definitions of descriptors was obtained through group discussion with the use of reference samples (Stone and Sidel 1985).

Cooked rice samples (40 g) cooled to room temperature were taken with a stainless ice cream scoop (6 cm diameter, Saejang Co., Seoul, Korea), placed in covered bowls (9 cm diameter × 4 cm depth), and presented to the panelists. Line scales (15 cm) with endpoints marked 1.25 cm from each end of the line (1.25 cm = weak, 13.75 cm = strong) were used to evaluate the intensity of each sensory attribute except chewiness. Chewiness was measured as the number of chews required for swallowing. All sensory evaluations were performed in individual booths under dim red light, except attributes for appearance, which were done separately under fluorescent light. Tap water purified as for the preparation of cooked rice was used to rinse between samples. Samples were served in random orders to panelists. A randomized complete block design with four replicates was used for the sensory evaluation of five cooked rice samples.

TABLE I
Reference Samples for Sensory Attributes of Cooked Rice[a]

Attribute	Weakest	Strongest
Appearance		
Color	White paper[b]	Cooked brown rice[c]
Glossiness	Milled rice	Cooked waxy rice[d]
Flavor		
Boiled egg white	…	Boiled egg white
Puffed corn	…	Puffed corn
Dairy	…	Pasteurized milk
Raw rice	…	Raw rice
Wet cardboard	…	Wet cardboard
Hay-like	…	Hay
Metallic	…	Stainless steel spoon
Sweet taste	…	Sucrose solution 2.0%
Bitter taste	…	Caffeine solution 0.05%
Texture		
Agglomeration	Cooked brown rice	Cooked waxy rice
Adhesiveness	Cooked brown rice	Cooked waxy rice
Roughness	Stick cheese, cheddar	Cooked brown rice
Hardness	Soybean curd, hard	Frankfurter sausage, fresh
Cohesiveness	Boiled egg white	Cooked waxy rice
Inner moisture	Bread, white	Soybean curd
Cohesiveness of mass	Fish gel	Cooked waxy rice
Chewiness	Ham	Frankfurter sausage, fresh
Toothpacking	Acorn starchy gel	Bread, white
Residuals	Acorn starchy gel	Bread, white

[a] Weakest = 1.25, strongest = 13.75.
[b] *L,a,b* values for white paper: 94.19, 1.03, and –1.72, respectively.
[c] Rice-to-water = 1:1.7.
[d] Rice-to-water = 1:1.1.

TABLE II
Definitions for Sensory Evaluation of Cooked Rice

Attribute	Definition
Appearance	
Color	Degree of yellowish color
Glossiness	Amount of shine on surface of cooked rice
Intactness of grains	Degree to which grains remain intact
Plumpness	Degree of plumpness of rice kernels
Flavor	
Boiled egg white	Aroma associated with sulfur compounds evolved from boiled egg white
Puffed corn	Aroma associated with puffed corn
Dairy	General term associated with aromatics of pasteurized cow's milk
Raw rice	General term used to describe aromatics in the flavor associated with grains such as raw rice
Wet cardboard	Aroma associated with wet cardboard
Hay-like	A dry, dusty flavor
Metallic	Aroma of minerals and metals commonly associated with metal spoon
Sweet taste	Fundamental taste sensation of which sucrose is typical
Bitter taste	Fundamental taste sensation of which caffeine or quinine is typical
Texture	
Degree of agglomeration	Degree to which the sample holds together when separated into individual pieces with chopsticks
Adhesiveness	Degree to which kernels adhere to the lips
Roughness	Amount of irregularities on surface of kernels (one or two passes with the tongue)
Stage 1: Place a spoonful of sample in the mouth; chew twice with molar teeth	
Hardness	Force required to compress cooked rice using the molar teeth
Cohesiveness	Degree to which sample deforms rather than breaks
Inner moisture	Amount of moisture inside the kernel released upon chewing
Stage 2: Place a spoonful of sample in mouth; chew with molar teeth 3 or more times	
Cohesiveness of mass	Degree to which mass holds together during mastication
Chewiness	Number of chews required to masticate cooked rice to be suitable for swallowing
Stage 3: Place a spoonful of sample in the mouth; evaluate after swallowing	
Toothpacking	Degree to which sample sticks on surfaces of molar teeth
Residuals	Amount of particles remaining in mouth after swallowing

Statistical Analysis

Physicochemical and sensory data were analyzed using analysis of variance (ANOVA) to determine the effect of milling ratio. Duncan's multiple range test ($\alpha = 0.05$) was done to separate the means. Principal component analysis (PCA) was used to summarize the effects of milling ratio on sensory characteristics of cooked rice. Correlation coefficients (r) were obtained between sensory characteristics of cooked rice and physicochemical characteristics of milled rice and cooked rice. All the statistical analyses were conducted using statistical software (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Physicochemical Characteristics of Milled Rice

The proximate compositions of rice with different milling ratios are shown in Table III. Moisture, protein, lipid, and ash contents decreased as the degree of milling increased. This could be explained by the removal of the caryopsis coat, aleurone, and subaleurone layers, which have high ash, lipid, and fiber contents (Villareal et al 1991; Kim 1994; Kim and Jeon 1996). Whiteness values of rice increased significantly as the degree of milling increased (Table III).

Pasting properties of rice flour slurries are shown in Table IV. The initial pasting temperature of rice flour tended to decrease with increased milling. Marshall et al (1990) and Champagne et al (1990) observed significantly reduced pasting temperatures with the removal of the outer layers of the kernel. The peak viscosity significantly increased ($P < 0.05$) and breakdown viscosity tended to increase with increased degree of milling. Setback viscosity, which indicates the degree of retrogradation (Mazurs et al 1957), showed a tendency to increase with increased milling. These results agree with those of Bhattacharya and Sowbhagya (1979) and Ghiasi et al (1982).

Physicochemical Characteristics of Cooked Rice

Moisture contents of cooked rice increased with increased milling while the amount of water evaporated during cooking decreased (Table V). The restriction of water absorption by protein (Watanabe et al 1990), fat (Kim et al 1986), and minerals (Juliano 1985b) have been reported. The increase of moisture content in cooked rice with increased milling appeared to be related to the increase of water absorption due to the removal of protein, lipids, and minerals.

Instrumental measurements of the texture of cooked rice revealed that hardness, springiness, and chewiness decreased while adhesiveness increased with increased milling (Table VI). Yanase et al (1984) reported that rice with higher protein content was lower in adhesiveness and in water-uptake ratio. Hardness of cooked rice could be affected by mineral (Juliano 1985b) and lipid contents (Kim et al 1986). The results of this study suggest that changes in textural properties of cooked rice were due to differences in proximate composition of rice from various milling ratios.

Descriptive Analysis of Cooked Rice

The sensory scores for cooked rice with different milling ratios are shown in Table VII. Significant differences ($P < 0.05$) in all the sensory attributes except metallic flavor and amount of residuals after swallowing were observed. Color was markedly lower with increased degree of milling. Glossiness and plumpness scores were highest at 12.5% milling but not significantly different among samples with over 11.0% milling. Intactness of grains decreased greatly as the degree of milling increased.

Intensity of boiled egg-white flavor was the lowest in the sample with 8% milling and the highest in the sample with 12.5% milling. Boiled egg-white flavor, which was described as sulfury by Meullenet et al (1999) and as sewer-animal-like by Champagne et al (1997), could be caused by volatile sulfur compounds in the rice (Tsuzuki et al 1978). Dairy flavor intensity was the lowest in 8% milled rice and there were no significant differences among the samples with 9.5% milling or more. Intensities of puffed corn, raw rice, wet cardboard, and hay-like flavors decreased with increased milling. It is well known that fatty substances are oxidized and hydrolyzed during storage of rice, resulting in stale flavors. Wet cardboard and hay-like flavors seemed to be related to oxidized fat substances in the rice. It seemed that rice samples with lower degrees of milling contained higher fat content, therefore giving higher scores of these flavor attributes. Sweet taste was more

TABLE III
Proximate Composition and Whiteness of Rice[a]

Degree of Milling (%)[b]	Moisture (%)	Crude Protein (%, dwb)[c]	Crude Fat (%, dwb)	Crude Ash (%, dwb)	Whiteness
8.0	15.4	6.65	0.55	0.42	35.02e
9.5	14.8	6.29	0.37	0.41	36.76d
11.0	15.0	6.27	0.24	0.32	40.16c
12.5	14.4	6.09	0.20	0.26	43.68b
14.0	14.2	5.92	0.19	0.26	44.44a

[a] Means of three replicates. Values within a column were not significantly different except in whiteness. Values for whiteness were all significantly different ($P < 0.05$).
[b] Based on brown rice.
[c] N × 5.95; dwb = dry weight basis.

TABLE V
Amount of Water Evaporated During Cooking and Moisture Content of Cooked Rice[a]

Degree of Milling (%)[b]	Water Evaporated (g)[c]	Moisture Content (%)
8.0	136.9a	61.0c
9.5	120.1b	61.3c
11.0	109.7bc	62.5b
12.5	125.0b	62.2b
14.0	95.5c	63.1a

[a] Means of three replicates. Values followed by the same letter in the same column are not significantly different ($P > 0.05$).
[b] Based on brown rice.
[c] Amount of water evaporated during cooking.

TABLE IV
Pasting Properties of Rice Flour Dispersion[a]

Milling (%)[c]	Pasting (°C)[d]	Viscosity (BU)[b]						
		Peak	95	95/15	50	Consistency	Breakdown	Setback
8.0	63.65	469.5c	300.0c	202.5c	369.0b	166.5	216.0	–100.5
9.5	63.45	488.5c	299.5c	202.0c	411.5b	209.5	286.5	–77.0
11.0	63.35	530.0b	353.0b	235.5b	475.5ab	240.0	294.5	–54.5
12.5	63.20	580.0a	425.0a	271.5a	531.5a	260.0	308.5	–48.5
14.0	63.15	586.5a	436.0a	274.5a	535.0a	260.5	312.0	–51.5

[a] Means of duplicates. Values followed by the same letter in the same column are not significantly different ($P > 0.05$). Values of consistency, breakdown, and setback were not significantly different. Dispersion = 8% (w/w).
[b] 95 = at 95°C; 95/15 = at 95°C after 15 min; 50 = at 50°C.
[c] Degree of milling based on brown rice.
[d] Initial pasting temperature.

TABLE VI
Instrumental Texture Profile of Cooked Rice[a]

Characteristic	Degree of Milling (%) 8.0	9.5	11.0	12.5	14.0
Hardness (g)	2,641a	2,181b	2,102bc	2,104bc	1,925c
Adhesiveness (g)	–454b	–369a	–299a	–341a	–342a
Springiness	0.83a	0.79a	0.81a	0.77ab	0.68b
Cohesiveness	0.19a	0.19a	0.17b	0.19a	0.20a
Chewiness (g)	426a	329b	297bc	312bc	264c
Resilience	0.10ab	0.10a	0.09b	0.10a	0.10a

[a] Means of three replicates. Values followed by the same letter in the same row are not significantly different ($P > 0.05$).

TABLE VII
Sensory Descriptive Profile of Cooked Rice[a]

Attribute[b]	Degree of Milling (%) 8.0	9.5	11.0	12.5	14.0
Appearance					
Color	11.34a	8.91b	7.31c	5.71d	4.43e
Glossiness	5.32c	7.83b	9.18a	9.93a	9.58a
Intactness of grains	10.84a	9.51b	8.05c	6.95d	5.39e
Plumpness	5.62c	6.92b	8.46a	9.46a	9.22a
Flavor					
Boiled egg white	5.28c	6.83ab	6.64b	7.99a	7.46ab
Puffed corn	10.02a	8.06b	7.44b	5.42c	4.66c
Dairy	5.09b	7.04a	6.70a	7.61a	7.16a
Raw rice	9.48a	7.73b	7.13b	5.68c	5.07c
Wet cardboard	10.19a	8.22b	7.33c	5.39d	4.56d
Hay-like	10.49a	8.43b	7.43c	5.61d	5.18d
Metallic	7.32a	7.25a	6.79a	6.68a	6.60a
Sweet taste	4.66d	6.06c	7.14b	8.63a	9.29a
Bitter taste	8.81a	7.55ab	7.12bc	5.73c	6.31bc
Texture					
Degree of agglomeration	4.49c	6.77b	7.62b	9.75a	10.23a
Adhesiveness	5.03c	7.15b	7.44b	9.38a	9.85a
Roughness	8.27a	7.20ab	7.02ab	7.80ab	6.72b
Hardness	10.46a	8.41b	7.50c	4.96d	3.94e
Cohesiveness	5.24d	7.50bc	7.33c	9.09a	8.73ab
Inner moisture	4.76c	6.99b	7.11b	9.74a	9.66a
Cohesiveness of mass	4.86d	6.70c	7.96b	9.88a	10.27a
Chewiness	18.18a	15.90b	15.75b	13.93c	14.40bc
Toothpacking	5.36c	7.42b	7.88ab	8.87a	8.91a
Residuals	7.54a	7.39a	7.61a	7.15a	7.12a

[a] Means of four replicates. Values followed by the same letter in the same row are not significantly different ($P > 0.05$).
[b] Sensory descriptive attributes (except chewiness) were evaluated on 15-cm line scales, where 1.25 cm = weak and 13.75 cm = strong; chewiness was evaluated on number of chews.

intense with the higher degree of milling and bitter taste with the lower degree of milling.

Degree of agglomeration, adhesiveness, and toothpacking were higher and hardness lower with the increased milling ratios. This result seemed to be associated with the higher water content in cooked rice samples (Kim et al 1995) with the higher degree of milling. Juliano et al (1965) reported that greater hardness and lower adhesiveness of cooked rice was related to rice with higher protein content. Insolubility of protein interrupts moisture absorption and swelling of starch granules during cooking of rice (Hamaker and Griffin 1990; Marshall et al 1990). Therefore, increased milling would result in decreased protein content, affecting textural changes as indicated above. Roughness decreased slightly with increased milling. Cohesiveness, inner moisture, and cohesiveness of mass markedly increased while chewiness decreased as the degree of milling increased. Champagne et al (1997) suggested that the effect of degree of milling on flavor intensities differs depending on initial moisture content, cultivar, and location. However, effects of these conditions with different degree of milling on the texture of cooked rice still remain to be studied.

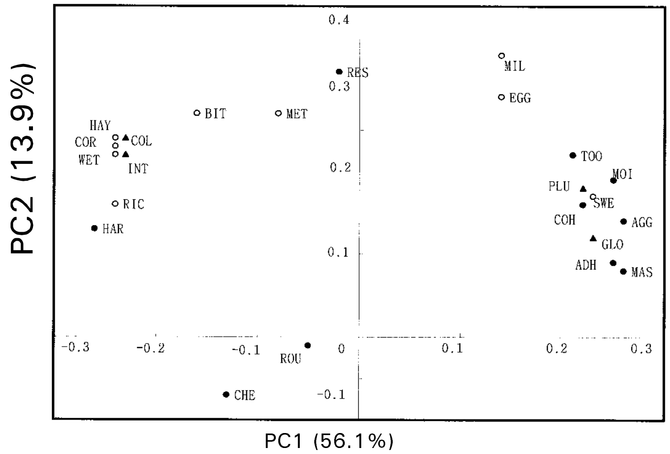

Fig. 1. Sensory characteristics of cooked rice on first (*x*) and second (*y*) principal components. COL = color, GLO = glossiness, INT = intactness of grains, PLU = plumpness, EGG = boiled egg-white flavor, COR = puffed corn flavor, MIL = dairy flavor, RIC = raw rice flavor, WET = wet cardboard flavor, HAY = hay-like flavor, MET = metallic flavor, SWE = sweet taste, BIT = bitter taste, AGG = degree of agglomeration, ADH = adhesiveness, ROU = roughness, HAR = hardness, COH = cohesiveness, MOI = inner moisture, MAS = cohesiveness of mass, CHE = chewiness, TOO = toothpacking, RES = residuals. (▲, ○, and ● = descriptive attributes for appearance, flavor, and texture, respectively).

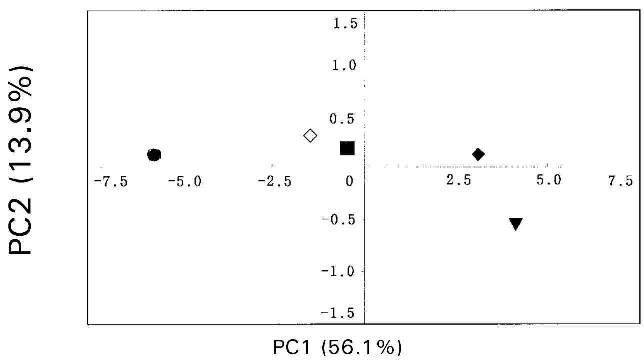

Fig. 2. Cooked rice samples on first (*x*) and second (*y*) principal components. (●,◇,■,◆, and ▼ = cooked rices prepared with 8, 9.5, 11, 12.5, and 14% degree of milling, respectively).

PCA was used to summarize the effect of milling degree on the sensory attributes of cooked rice. First (PC1) and second (PC2) principal components accounted for 70% of the variance. The rotated factor loadings for 23 sensory attributes on PC1 (*x*) and PC2 (*y*) dimensions are presented in Fig. 1. Degree of agglomeration, cohesiveness of mass, adhesiveness, inner moisture, tooth packing, glossiness, color, plumpness, cohesiveness, and sweet taste were loaded positively on PC1, whereas hardness, intactness of grains, raw rice flavor, wet cardboard flavor, puffed corn flavor, hay-like flavor, and color loaded negatively on PC1. The attributes loaded in the same direction indicate positive correlation with each other. Cooked rice samples with different ratios of milling are shownon the PC1 (*x*) and PC2 (*y*) dimension (Fig. 2). The milled rice with 12.5 and 14% milling loaded positively while that with 8% milling loaded negatively on PC1.

Correlation coefficients (*r*) between sensory attributes and physicochemical measurements are shown in Table VIII. Color, intactness of grains, puffed corn flavor, raw rice flavor, wet cardboard flavor, and hay-like flavor intensity by panelists were positively correlated with hardness (r = 0.76–0.83), chewiness (r = 0.76–0.81), moisture content (r = 0.87–0.94), protein (r = 0.90–0.94), and fat (r = 0.84–0.90). Sweet taste, degree of agglomeration, adhesiveness, cohesiveness, and cohesiveness of mass had positive correlation with whiteness (r = 0.81–0.97), and negative correlation with instru-

TABLE VIII
Correlation Coefficients (*r*) Between Physicochemical Characteristics and Sensory Descriptive Attributes[a]

Attribute[b]	Physicochemical Characteristics										
	HA	AD	SP	CO	CH	RE	WH	MO	PR	FA	AS
COL	0.82	–0.58	0.63	0.03	0.81	–0.04	–0.96	0.88	0.93	0.90	–0.40
GLO	–0.89	0.71	–0.58	–0.09	–0.88	0.07	0.89	–0.85	–0.91	–0.98	0.16
INT	0.81	–0.51	0.65	–0.05	0.78	–0.12	–0.96	0.87	0.92	0.88	–0.45
PLU	–0.80	0.64	–0.50	–0.04	–0.75	0.07	0.86	–0.70	–0.75	–0.91	0.04
EGG	–0.62	0.53	–0.23	–0.04	–0.50	0.12	0.41	–0.49	–0.40	–0.52	–0.34
COR	0.78	–0.49	0.71	–0.12	0.76	–0.17	–0.95	0.91	0.94	0.85	–0.42
DAI	–0.74	0.60	–0.61	0.08	–0.69	0.32	0.54	–0.71	–0.60	–0.61	–0.24
RIC	0.83	–0.54	0.74	–0.08	0.80	–0.19	–0.94	0.92	0.91	0.89	–0.24
WET	0.80	–0.53	0.78	–0.11	0.79	–0.22	–0.96	0.94	0.92	0.84	–0.33
HAY	0.76	–0.52	0.69	–0.03	0.77	–0.07	–0.94	0.89	0.90	0.84	–0.38
MET	0.18	–0.24	0.02	0.12	0.21	–0.03	–0.09	0.20	0.30	0.24	0.10
SWE	–0.86	0.63	–0.65	0.05	–0.81	0.17	0.96	–0.90	–0.91	–0.88	0.31
BIT	0.67	–0.65	0.59	0.11	0.71	–0.13	–0.80	0.79	0.75	0.67	–0.08
AGG	–0.84	0.58	–0.77	0.10	–0.83	0.26	0.96	–0.94	–0.96	–0.89	0.28
ADH	–0.83	0.58	–0.67	0.16	–0.78	0.30	0.89	–0.89	–0.95	–0.91	0.21
ROU	0.34	–0.24	0.01	–0.03	0.22	0.02	–0.02	0.05	0.03	0.26	0.35
HAR	0.80	–0.48	0.75	–0.15	0.76	–0.24	–0.97	0.93	0.90	0.84	–0.35
COH	–0.81	0.57	–0.63	0.07	–0.77	0.17	0.81	–0.87	–0.83	–0.85	0.09
MOI	–0.70	0.53	–0.58	–0.18	–0.76	–0.10	0.86	–0.67	–0.78	–0.76	0.50
MAS	–0.82	0.59	–0.64	–0.01	–0.81	0.11	0.97	–0.88	–0.93	–0.91	0.32
CHE	0.79	–0.63	0.63	–0.08	0.77	–0.13	–0.88	0.87	0.90	0.87	–0.14
TOO	–0.85	0.67	–0.50	0.02	–0.79	0.08	0.81	–0.78	–0.81	–0.91	0.10
RES	0.37	–0.01	0.43	–0.25	0.25	–0.40	–0.44	0.45	0.31	0.28	–0.19

[a] HA = hardness, AD = adhesiveness, SP = springiness, CO = cohesiveness, CH = chewiness, RE = resilience, WH = whiteness, MO = moisture, PR = protein, FA = fat, AS = ash, COL = color, GLO = glossiness, INT = intactness of grains, PLU = plumpness, EGG = boiled egg white, COR = puffed corn, DAI = dairy, RIC = raw rice, WET = wet cardboard, HAY = hay-like, MET = metallic, SWE = sweet taste, BIT = bitter taste, AGG = degree of agglomeration, ADH = adhesiveness, ROU = roughness, HAR = hardness, COH = cohesiveness, MOI = inner moisture, MAS = cohesiveness of mass, CHE = chewiness, TOO = toothpacking, and RES = residuals.

[b] Sensory descriptive attributes.

mental hardness (*r* = –0.86 to –0.81), moisture (*r* = –0.94 to –0.87), protein (*r* = –0.96 to –0.83), and fat content (*r* = –0.91 to –0.85). The correlation coefficients between sensory hardness of cooked rice and moisture, protein, and fat contents of rice were 0.93, 0.90, and 0.84, respectively. Consequently, the high correlation coefficients between sensory characteristics of cooked rice and whiteness, moisture, protein, and fat contents in this study confirmed previous reports by Yanase and Ohtsubo (1985), Kim et al (1986), Lee and Osman (1991), and Rousset et al (1995). There was high correlation between instrumental parameters and sensory attributes in hardness (*r* = 0.80) and chewiness (*r* = 0.77), indicating that instrumental measurement could replace sensory analysis for these parameters.

CONCLUSIONS

The results of the present study showed that degree of milling had significant effect on the sensory and the physicochemical characteristics of milled rice and cooked rice. Principal component analysis on sensory attributes of cooked rice indicated that cooked rice samples with the higher degree of milling had greater intensities of degree of agglomeration, cohesiveness of mass, adhesiveness, inner moisture, tooth packing, glossiness, color, plumpness, cohesiveness, and sweet taste. However, the samples with the lower degree of milling were weaker in intactness of grains, raw rice flavor, wet cardboard flavor, puffed corn flavor, hay-like flavor, and color. The high correlations between sensory characteristics of cooked rice and proximate composition agreed with previous studies by Yanase and Ohtsubo (1985), Kim et al (1986), Lee and Osman (1991), and Rousset et al (1995). To confirm the effect of degree of milling on the sensory characteristics of cooked rice, further descriptive analysis of cooked rice with different conditions such as cultivar, growing location, and initial moisture content of rice, are needed.

ACKNOWLEDGMENTS

This work was supported by a grant from Agriculture Research Promotion Center, Ministry of Agriculture and Forestry, Republic of Korea.

LITERATURE CITED

AOAC. 1995. Official Methods of Analysis of the Association of Official Analytical Chemists. 16th ed. Method 992.23; Method 920.39C; Method 923.03. The Association: Washington, DC.

Bhattacharya, K. R., and Sowbhagya, C. M. 1979. Pasting behavior of rice: A new method viscograph. J. Food Sci. 44:797-800.

Champagne, E. T., Bett, K. L., Vinyard, B. T., Webb, B. D., McClung, A. M., Barton, F. E., Lyon, B. G., Moldenhauer, K., Linscombe, S., and Kohlwey, D. 1997. Effect of drying conditions, final moisture content and degree of milling on rice flavor. Cereal Chem. 74:566-570.

Champagne, E. T., Marshall, W. E., and Goynes. W. R. 1990. Effects of degree of milling and lipid removal on starch gelatinization in the brown rice kernel. Cereal Chem. 67:570-574.

Chrastil, J. 1989. Chemical and physicochemical changes of rice during storage at different temperatures. J. Cereal Sci. 11:71-85.

Cross, H. R., Moen, R., and Stanffield, M. S. 1978. Training and testing of judges for sensory analysis of meat quality. Food Technol. 32:48-54.

Desikachar, H. S. R., Raghavendra, R. S. N., and Ananthachar, T. K. 1965. Effect of degree of milling on water absorption of rice during cooking. J. Food Sci. Technol. 2:110-112.

Ghiasi, K., Varriano-Marston, E., and Hoseney, R. C. 1982. Gelatinization of wheat starch. IV. Amylograph viscosity. Cereal Chem. 59:262-265.

Hamaker, B. R., and Griffin, V. K. 1990. Changing the viscoelastic properties of cooked ice through protein disruption. Cereal Chem. 67:261-264.

Juliano, B. O. 1985a. Criteria and tests for rice grain qualities. Pages 443-524 in: Rice Chemistry and Technology, 2nd Ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

Juliano, B. O. 1985b. Polysaccharide, proteins and lipids of rice grain composition. Pages 59-174 in: Rice Chemistry and Technology, 2nd Ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

Juliano, B. O., Onate, I. U., and Delmondo, A. M. 1965. Relation of starch composition, protein content, gelatinized temperature to cooking and eating qualities of milled rice. Food Technol. 19:1006-1011.

Kim, K. A., and Jeon, E. R. 1996. Physicochemical properties and hydration of rice on various polishing degrees. Kor. J. Food Sci. Technol. 28:959-964.

Kim, S. L. 1994. Effect of protein of rice on gelatinization of starch and textural characteristics of cooked rice. PhD thesis. Seoul National University: Seoul, Korea.

Kim, S. M., Kim, K. O., and Kim, S. K. 1986. Effect of defatting on

gelatinization of starch and cooking properties of Akibare (Japonica) and Milyang 30 (J-indica) milled rice. Kor. J. Food Sci. Technol. 18:393-397.
Kim, W. J., Chung, N. Y., Kim, S. K., Lee, A. R., Lee, S. K., Ha, Y. C., and Baik, M. Y. 1995. Sensory characteristics of cooked rices differing in moisture contents. Kor. J. Food Sci. Technol. 27:885-890.
Kwon, Y. W., and Jeon, W. B. 1991. Effect of period and store house grade in grain storage and degree of milling on the sensory taste of cooked rice. Kor. J. Crop Sci. 36:271-279.
Lee, Y. E., and Osman, E. M. 1991. Physicochemical factors affecting cooking and eating qualities of rice and the ultrastructural changes of rice during cooking. J. Kor. Soc. Food Nutr. 20:637-645.
Marshall, W. E. 1992. Effect of degree of milling of brown rice and particle size of milled rice on starch gelatinization. Cereal Chem. 69:632-636.
Marshall, W. E., Normand, F. L., and Goynes, W. R. 1990. Effects of lipid and protein removal on starch gelatinization in whole grain milled rice. Cereal Chem. 67:458-463.
Mazurs, E. G., Scoch, T. J., and Kite, F. E. 1957. Graphical analysis of the Brabender viscosity curves of various starches. Cereal Chem. 34:141-152.
Medcalf, D. G., and Gilles, K. A. 1965. Wheat starch. I. Comparison of physicochemical properties. Cereal Chem. 42:558-568.
Meullenet, J. C., Marks, B. P., Griffin, K., and Daniels, M. J. 1999. Effects of rough rice drying and storage conditions on sensory profiles of cooked rice. Cereal Chem. 76:483-486.
Morrison, W. R., and Azudin, M. N. 1987. Variation in the amylose and lipid contents and some physical properties of rice starches. J. Cereal Sci. 5:35-44.
Rousset, S., Pons, B., and Pilandon, C. 1995. Sensory texture profile, grain physico-chemical characteristics and instrumental measurements of cooked rice. J. Texture Stud. 26:119-135.
Stone, H., and Sidel, J. 1985. Page 215 in: Sensory Evaluation Practices. Academic Press: Orlando, FL.
Suzuki, H. 1979. Use of the texturometer for measuring the texture of cooked rice. Pages 327-341 in: Proc. Workshop on Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst.: Los Banos, Laguna, Philippines.
Tsuzuki, E., Matsuki, C., Morinaga, K., and Shida, S. 1978. Studies on the characteristics of scented rice. IV. Volatile sulfur compounds evolved from cooked rice. Jpn. J. Crop Sci. 47:375-380.
Villareal, C. P., Maranville, J. W., and Juliano, B. O. 1991. Nutrient content and retention during milling of brown rices from the International Rice Research Institute. Cereal Chem. 68:437-440.
Watanabe, M., Yoshizawa, T., Miyakawa, J., Ikezawa, Z., Abe, K., Yanagisawa, T., and Arai, S. 1990. Quality improvement and evaluation of hypoallergenic rice grains. J. Food Sci. 55:1105-1107.
Yanase, H., and Ohtsubo, K. 1985. Relation between rice milling methods and palatability of cooked rice. I. Relation between the quality and physico-chemical properties of milled rice and textural parameters of cooked rice. Nat. Food Res. Ins. 46:148-161.
Yanase H., Ohtsubo, K., Hashimoto, K., Sato, H., and Teranishi, T. 1984. Correlation between protein contents of brown rice and textural parameters of cooked rice and cooking quality of rice. Nat. Food Res. Ins. 45:118-122.

[Received November 19, 1999. Accepted November 13, 2000.]