Authentication of Rice by Three-Sided Image Analysis of Kernels Using Two Mirrors

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ABSTRACT

The authentication of rice by imaging three sides (top, side, and front) of a rice kernel using two mirrors was attempted. Nine image characteristics (area, aspect ratio, minimum diameter, maximum diameter, perimeter, and red, green, and blue values) for each side of a rice kernel were measured. Japonica type rices were used for the study; a total of 89 rice samples were used: 40 samples harvested in Korea, 33 in America, 5 in Australia, and 11 in China. Image data collected from 105 kernels per rice sample were used as a calibration data set to develop a model for quadratic discriminant analysis. In overall pairwise trials, on average, 85.8–94.5% correct identification of the cultivated country was obtained, depending on the number of image characteristics used for the discriminant model. For the effective discrimination of the cultivated country, 13 image characteristics were selected. As a test sample set, 20 kernels per sample were used. A model for discriminant analysis with 13 image characteristics yielded an average of 95.0 and 97.5% accuracy for calibration and test sample set, respectively.

According to World Trade Organization agreements, Korea and Japan are gradually opening their rice market to the world. Even though the price of rice is different depending on the country, the imported rice in Korea and Japan is much cheaper than rices grown in those countries. Because of the difference in price between imported and domestic rice, imported rice can be forged or mixed into domestic one. The illegal marketing of rice might damage the image of the cultivating country, where quality control of rice is well maintained. Therefore, techniques for authentication of rice are essential to prevent illegal marketing of rice.

The milling process and inspection guidelines for milled rice are different, depending on the country. For example, milled rice coated with glucose or enriched with certain vitamins, which is common in the United States, is not found in Korea. Those differences might affect the physical appearance of milled rice. As Symons and Fulcher (1988) mentioned, grain morphology also might be greatly affected by environmental conditions. Therefore, the physical appearance of rice might be different depending on the country of origin.

Image analysis can be used for quantifying the physical appearance of grain and has been used for kernel classification and discrimination by using a video camera interfaced to computer systems for image capture and analysis (Zayas et al 1985, Lai et al 1986, Zayas et al 1986, Neuman et al 1987, Ryuji 1992). Chen et al (1989) developed a system with a laser scanning device to improve the limited information of a two-dimensional image. When the discrimination of wheat cultivars Daws (soft white winter) and Tyee (club) were made with the combination of 14 features based on nine topographic images and five intensity images, 92–94% of the kernels were correctly identified (Thomson 1991).

Even though information from a three-dimensional image was proven to be better than that of a two-dimensional image, the software to interpret the image by laser scanning device is not commercially available. A mirror could be used for collecting side or front images of a kernel, where image features can be measured by commercially available software for image analysis.

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Although, image analysis has been attempted for wheat variety identification, reports on authentication of rice by image analysis is limited. The purpose of this study was to investigate the possibility for authenticating rice by using three side images (top, side, and front) of a rice kernel using two mirrors, as a simple and low cost method.

MATERIALS AND METHODS

Materials

A total of 89 rice samples were used for the study. Forty typical milled rices harvested in Korea were collected through the Rural Development Administration (Suwon City, Korea) under the Department of Agriculture in Korea. In addition to Korean rice, 11 rice samples from China, 33 from America, and 5 from Australia were included. All of them were commercially available japonica-type rice harvested in 1994, except the Australian rice, which was harvested in 1995. Rice samples from China were harvested in Manchuria. Australian rice samples harvested in the Riverina district, were obtained through the Rice Growers Co-Operatives Ltd. (Sydney, Australia). Thirty-three rice samples from America were harvested in California (23 samples), Texas, Louisiana, and Arkansas.

Image Analysis System

The image analysis system consisted of four parts; image acquisition system, image analysis hardware, image output hardware, and image analysis software. The image acquisition system (Micro Hi-scope, Hirox Co., Ltd., Japan) consisted of a main control box (model KH-2200MD2) and a zoom lens (MX-2012Z) attached to the charge coupled (CCD, 0.5 in.) camera with optic fiber. An image was magnified 20×. The effective pixel resolution was 764(H) × 493(V) and the *f*-stop was constant throughout the experiment. The color frame grabber (Imascan Chroma/V, Japan) was used for image analysis hardware. A personal computer (586-66MHz, Sambo Computer, Inc., Korea) with 32 megabyte random access memory (RAM) was used for image output. The software for image analysis was Image Pro ver 1.3 (Media Cybernetics).

Conditions for Image Acquisition

To capture three-sided images of a kernel, two mirrors were placed on the stage with a 55° angle. The top, side, and front images of rice were captured as in Fig. 1. The area, aspect ratio, maximum diameter, minimum diameter, perimeter, red (*R*), green (*G*), and blue (*B*) values of the rice image were obtained from all three sides. To prevent external light sources from affecting the color of rice samples, the image analyzer was placed in a dark room. The light sources were two fluorescent lamps (model FPL 14EX-N, Samyouk Electric Co., Korea).

Correlation Between Colors Measured by Colorimetry and Image Analysis

The correlation between color (*Y*, *x*, and *y*) measured by colorimetry (Minolta, CR-200) and by image analysis (*R*, *G*, and *B*) was detemined. Three measurements were made for 77 color standards (KSG2510, Hangook Color, Korea). The *R*, *G*, and *B* values from image analysis were transformed to *Y*′, *x*′ and *y*′ values by the methods of Park (1994), and the colors were correlated by colorimetry and image analysis.

Transformation of *R*, *G*, and *B* system to *XYZ* system:

$$X = -0.490R + 0.310G + 0.200B$$
$$Y = 0.177R + 0.813G + 0.011B$$
$$Z = 0.000R + 0.010G + 0.990B$$

Transformation of *XYZ* system to *Yxy* system:

$$Y = Y$$
$$x = X / (X + Y + Z)$$
$$y = Y / (X + Y + Z)$$
$$z = Z / (X + Y + Z)$$

Statistical Analysis

As a calibration data set, 27 image characteristics on 105 rice kernels for each of the 89 rice samples (40 rice samples grown in Korea, 33 in America, 5 in Australia, and 11 in China) were used. For discrimination of the cultivating country, quadratic discriminant analysis was performed using SAS (1988). Statistical analysis consisted of four steps: 1) image characteristics were ranked depending on the importance for the authentication of rice, using primary, forward stepwise, and backward stepwise discriminant analysis; 2) discriminant equations with various image characteristics in the order of the importance were prepared and the average accuracy (%) of the discriminant equations were determined using 6–27 image characteristics (number of image characteristics for discriminant equations was selected depending on the efficiency of the discriminant equations); 3) quadratic discriminant analysis with the selected number of image characteristics was conducted and the percentage of correctly identified samples from cultivating country was calculated; 4) discrimination analysis was confirmed with 20 randomly selected kernels per sample.

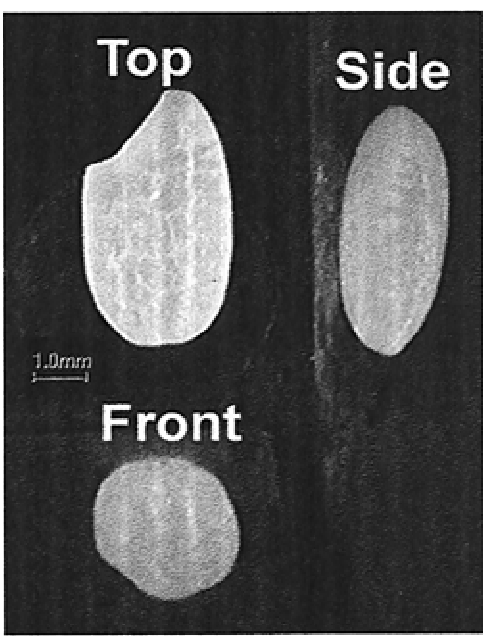

Fig. 1. Three-sided (front, side, and top) images of a rice kernel used for the study.

RESULTS AND DISCUSSIONS

Correlation Coefficients (*r*) Between Colors Measured by Colorimetry and Image Analysis

The correlation coefficients (*r*) between colors measured by colorimetry (*Y*, *x*, and *y*) and image analysis (*Y*′, *x*′, and *y*′) were: *Y* and *Y*′ ($r = 0.95$), *x* and *x*′ ($r = 0.88$), and *y* and *y*′ ($r = 0.78$). The linear regression equations and R^2 between colors are:

$$Y = 0.32\, Y' - 17.45 \qquad (R^2 = 0.89)$$
$$x = 7.76\, x' - 2.25 \qquad (R^2 = 0.69)$$
$$y = 4.13\, y' - 1.09 \qquad (R^2 = 0.60)$$

The results showed relatively low R^2 values, especially for *y* and *y*′, implying different color values depending on the methods. It seemed that the color values measured by image analysis were not compatible to those measured by colorimetry. While fluores-

TABLE I
Accuracy (%) in Identifying Rice by Cultivating Country Depending on Numbers of Image Characteristics for Discriminant Analysis with Calibration Data Set

No. of Image	Accuracy(%) of Identifying Cultivated Country				
Characteristics[a]	Australia	China	Korea	USA	Average
27	97.3	94.4	92.2	93.9	94.5
26	98.1	95.0	93.1	94.3	95.1
25	98.1	95.6	92.9	94.0	95.2
24	99.1	95.8	93.4	94.4	95.7
23	98.7	95.4	93.3	94.5	95.5
22	99.1	95.3	93.1	94.2	95.4
21	98.9	95.2	93.0	94.3	95.4
20	98.3	95.0	93.0	94.7	95.3
19	98.1	94.8	92.9	94.6	95.1
18	97.7	94.9	93.0	94.8	95.2
17	97.5	95.2	93.1	94.7	95.1
16	97.7	94.6	93.3	94.6	95.1
15	98.3	94.7	93.1	95.0	95.3
14	97.7	94.6	92.8	94.8	95.0
13	98.1	94.8	92.3	94.8	95.0
12	97.5	94.3	91.9	94.6	94.6
11	97.7	93.9	90.3	94.6	94.1
10	96.4	93.5	87.4	91.3	92.2
9	95.2	91.3	87.8	91.1	91.4
8	94.7	90.7	87.4	89.5	90.6
7	95.1	88.7	87.4	81.9	88.3
6	91.6	85.4	86.7	79.3	85.8

[a] Order of image characteristics used for discriminant analysis: x12, x9, x19,x18, x16, x7, x25, x27, x4, x6, x17, x8, x26, x3, x1, x22, x24, x13, x2, x10, x11, x14, x20, x21, x5, x15, x23. x1–x9 (top image); x10–x18 (side image); x19–x27 (front image) area, aspect, maximum diameter, minimum diameter, perimeter, roundness, red, green, and blue intensity.

TABLE II
Results of Discrimination Analysis of Rice by Cultivating Country

	Accuracy(%) of Identifying Cultivated Country			
	Australia	China	Korea	USA
Calibration data				
Australia	98.1	1.3	0.4	0.2
China	2.6	94.8	1.7	0.9
Korea	0.6	4.8	92.3	2.3
USA	1.6	1.2	2.5	94.7
Test data				
Australia	100	0	0	0
China	0	100	0	0
Korea	0.5	3.3	94.8	1.4
USA	2.9	0.6	2.3	94.2

TABLE III
Mean Values of 13 Image Characteristics of Rice by Cultivating Country Using Calibration Data Set

Image Characteristics	Australia		China		Korea		USA	
	Mean	SE[a]	Mean	SE	Mean	SE	Mean	SE
Top								
Minimum dia.(mm)	2.74	0.005	2.94	0.004	2.84	0.002	2.82	0.003
Roundness[b]	1.38	0.001	1.28	0.001	1.32	0.001	1.41	0.001
Red	214.8	0.32	219.2	0.17	212.4	0.098	221.1	0.12
Green	224.5	0.28	228.6	0.17	222.8	0.096	232.2	0.12
Blue	212.8	0.27	217.2	0.17	210.9	0.12	221.4	0.11
Side								
Maximum dia. (mm)	5.39	0.010	4.89	0.008	4.951	0.004	5.76	0.008
Red	198.7	0.30	199.4	0.18	194.2	0.09	203.9	0.12
Green	207.1	0.20	208.0	0.19	204.6	0.09	213.1	0.12
Blue	200.3	0.20	202.4	0.18	199.4	0.10	207.0	0.11
Front								
Area (mm^2)	6.11	0.020	6.40	0.015	6.20	0.004	6.67	0.010
Red	178.9	0.30	187.4	0.19	181.9	0.11	190.7	0.14
Green	190.9	0.40	199.6	0.21	194.0	0.12	203.6	0.15
Blue	184.5	0.4	193.6	0.21	187.0	0.12	197.7	0.13

[a] Standard error of the means.
[b] Roundness = (perimeter)/ $4\pi \bullet$ area.

cent light was used for image analyzer, pulsed xenon lamp was used for colorimetry as light source. As Park et al (1994) explained, inconsistent results on color might be caused by the use of different light sources. To obtain reliable color values by image analysis, further research on light source and measuring conditions needs to be done.

Discrimination Among Cultivating Countries

The average correct classification scores for rice from different cultivating countries varied from 94.5 to 85.8% depending on the number of image characteristics considered (Table I). The number of image characteristics of rice kernels was determined by the efficiency of the discriminant analysis. Thirteen was chosen as the minimum number of image characteristics for maximum accuracy. The characteristics were: minimum diameter; roundness; *R*, *G*, and *B* values of top image; maximum diameter; *R*, *G*, and *B* values of the side image; area; and *R*, *G*, and *B* values of the front image of the kernel.

When Neuman et al (1989) performed discriminant analysis based on *R*, *G*, and *B* pixel reflectance features obtained by color digital image analysis. The overall average correct classification for hard red spring type of wheat kernels was ≈90%. As in the report by Neuman et al (1989), the results of this study indicated that color of the rice kernel was an important factor for discrimination of cultivating countries.

The percentage of correct identification among cultivating countries by discriminant analysis with 13 image characteristics are shown in Table II. Discriminant analysis with calibration data showed that correct identification (%) for rice grown in Australia, China, Korea, and the United States was 98.1, 94.8, 92.3, and 94.8%, respectively. The percentage of misclassification of Australian rice as Chinese rice was 1.3%, and misclassification of Chinese rice as Australian rice was 2.6%. Among Korean rices, 4.8 and 2.3% were misclassified as Chinese and U.S. rice, respectively. The percentage of U.S. rice misidentified as Korean rice was 2.5%.

With the test samples, the average percentage for correct identification of the cultivating countries was 98.2%. All of the rice grown in Australia and China were correctly identified. The percentages of correct identification for rices grown in Korea and the United States were 94.8 and 94.2%, respectively. The misidentification percentages for Korean rice as Chinese and U.S. rice were 3.3 and 1.4%, respectively. Among test samples, 2.9 and 2.3% of U.S. rice was misclassified as Australian and Korean rice, respectively.

All of the rice samples used for this study were representative of both short and medium grain rice for each country, except those from China. All of the Chinese rice samples were obtained from one province (near Manchuria), which is the major cultivating site for japonica type rice. Recently, the cultivation area for japonica type rice in China has been increased and extended into the southern part of China (Park 1996). Because of the limitation in sampling from China, the discriminant model over a wider range of cultivating sites in China remains to be validated.

As shown in Table III, among 13 image characteristics chosen for discriminant analysis, 9 were related to colors, indicating the importance of color for identification. The color of rice can be affected by various factors including cultivating area, processing conditions, and inspection guidelines, etc. It was clearly shown in U.S. rice, which had higher *R*, *G*, and *B* values. In spite of the limitation, the results of this study suggest that image analysis using two mirrors on three sides of a rice kernel can be successfully used for authentication of rice.

CONCLUSION

When the authentication of rice using images from three sides (front, side and top) of a kernel was attempted, 13 image characteristics out of 27 image characteristics were chosen for the discriminant analysis model. Nine out of 13 image characteristics were related to colors, showing that color of the rice kernel was important for discrimination of the cultivating countries. Results of this study showed that authentication of rice by image analysis using two mirrors was successful, even though discriminant analysis with wider range of Chinese rice still need to be confirmed.

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