Determination of rice milling ratio by visible/near infrared spectroscopy

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Introduction

The purpose of rice milling is to produce an edible polished or white rice produce from harvested, dried rough rice. The degree of milling is an important factor related to the quality and nutritional value of the milled rice and to the economic return to the rice processor. Physical methods for determining the degree of milling have generally utilised the optical properties of rice. These methods depend on the reflection of light from, or the transmission of light through, the milled rice at selected wavelengths. Near infrared (NIR) spectroscopic techniques can be used to estimate the degree of milling as a grading tool.[3,6] The NIR degree of milling calibration equation was developed using spectra measured with whole and kernel rice samples.[4] Partial least squares (PLS) analysis produced better degree of milling calibration equations than multiple linear regression (MLR) analysis. However, the use of PLS analysis for on-line control of rice-milling machines is probably not practical due to the higher cost of NIR scanning monochromators compared with filter instruments. The spectral reflectance of paddy, brown rice, milled rice, greenish grain, yellow grain and denatured grain were measured over the range of 340–820 nm.[1] Variation in the reflectance, depending on the milling degree of milled rice, appeared greatest over the range of 420 to 500 nm and that between white rice and other rice sample appeared greatest near 500 nm.

The objectives of this study were to develop models to determine the milling ratio of rice by visible and NIR spectroscopic techniques.

Materials and methods

Twelve kinds of brown rice, three varieties from four different provinces, were tested in this study. Three rice varieties used were Dongjin from Kyungnam, Kyungbuk, Chunbuk and Chungnam provinces, Hwoasung from Kyungbuk, Chunnam, Kyunggi and Kangwon provinces and Ilpum from Kyungbuk, Chungnam, Chungnam and Kyunggi provinces. The rices were harvested in the fall of 1995, shipped to the laboratory in 1996, held in polyethylene bags and stored in the storage facility at 4°C during experiments. Before husking, the rice samples were left at room temperature for 24 hours to reach the room temperature. The temperature of the rice was not measured or controlled during measurement.

Paddy rices were husked by a husker (Satake, THU35A, Japan) and normal brown rices were separated by a 1.7 mm sieve and a separator (Satake, TRCO5A, Japan). The brown rices were milled by a tester miller (Toyo, MC-90A, Japan) to obtain various milling ratios in the range of 86%–94% with interval of 0.5% to 1% and then the weight of the milled rice was measured. Rice milling ratio can be expressed as follows:

$$\text{Milling ratio (\%)} = \frac{\text{Weight of milled rice (g)}}{\text{Weight of brown rice (g)}} \times 100$$

A spectrophotometer, equipped with a single-beam scanning monochromator (NIRSystems, Model 6500, USA) and a sample transport module, was used to collect spectral data from each sample. The reflectance and transmittance spectra were measured in wavelength ranges 400–2498 nm with 2 nm intervals. Thirty-two repetitive scans were averaged, transformed to log(1/*R*) and were then stored in a microcomputer file, forming one spectrum per measurement.

Ten to twelve rice samples per each kind of brown rice were selected by milling ratios. A total of 149 rice samples were selected and used to measure both reflectance and transmittance spectra. To keep density of samples constantly, 120 g of rice samples were poured freely from a given height during measurement of transmittance spectra.

One hundred and forty nine spectra were divided into a calibration set and a validation set. 92 spectra were used for the calibration set and 57 spectra were for the validation set. MLR, PLS and artificial neural network (ANN) were used to develop models. Commercial software packages, NSAS 4.0 (NIRSystems, USA) and GRAMS/32 (Galactic Industries, Salem, New Hampshire, USA), were used to perform the analyses. The first and the second derivatives of raw spectra were also used to develop the models with proper smoothing gap. The multiplicative scatter correction (MSC) and the standard normal variate and detrend (SNVD) preprocessing were applied to all spectra to minimise sample-to-sample light scatter differences. On completion of the calibration, the models were used to predict the milling ratio of the rice from the validation set. Model performance was reported as the coefficient of determination (R^2), the standard error of prediction (*SEP*) and the average difference between measured and predicted values(bias).

Results and discussion

In the visible range, the absorption of the brown rice was greater than that of milled rice and decreased as the milling ratio of brown rice was reduced. In the NIR range, the absorption of the brown rice was the lowest and that of milled rice was increased as their milling ratio was increased. Reflectance and transmittance spectra were measured in wavelength ranges of 400 to 2498 nm with

Table 1. Results of MLR model for milling ratio of rice by reflectance.

Math treatment	Preprocess	No. of wavelengths	Calibration		Validation		
			R^2	*SEC*	R^2	*SEP*	Bias
None	None	6	0.984	0.420	0.977	0.577	0.019
	SNVD	6	0.978	0.488	0.967	0.697	–0.039
1st derivative	None	6	0.984	0.416	0.980	0.535	0.069
	SNVD	6	0.976	0.510	0.964	0.724	–0.078
2nd derivative	None	6	0.980	0.465	0.967	0.701	0.092
	SNVD	6	0.980	0.473	0.969	0.802	–0.073

2 nm intervals. The transmittance spectra had lots of noise in the NIR range, so transmittance spectra were analysed in wavelength ranges 600–1398 nm for model development.

The MLR model, using the first derivative reflectance spectra, showed the best results to predict the milling ratio of rice. The wavelengths selected for the MLR model were 404, 1184, 1216, 732, 1734 and 1864 nm from the first derivative spectra with 4 nm of smoothing size and 8 nm of gap. The MLR model had 0.980 R^2 and 0.535% *SEP* as shown in Table 1 and Figure 1. Performance results of the MLR model for transmittance spectra were similar to those of reflectance spectra. The wavelengths selected for the MLR transmittance model were 610, 664, 684, 692, 968 and 1228 nm from the first derivative spectra with 4 nm of smoothing size and 8 nm of gap. R^2 was 0.963 and *SEP* was 0.724%.

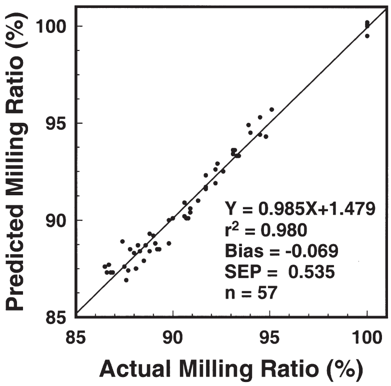

Figure 1. Comparison of actual and predicted values of milling ratio by MLR reflectance model.

The PLS analyses showed a good correlation between reflectance spectra and milling ratios of rice. As shown in Table 2, the PLS model, using raw spectra without preprocessing, showed the best result but used too many factors. This means that that the model may include systematic noise to predict the milling ratios from unknown rice samples. The PLS model, using raw spectra with MSC preprocessing, showed the best performance by using four factors. The PLS model had 0.976 R^2 and 0.604% *SEP* as shown in Figure 2. The PLS model for transmittance spectra also showed good results in predicting the milling ratios of the rice. The PLS model, using raw transmittance spectra without preprocessing, had 0.964 R^2 and 0.720% *SEP.*

The ANN model was developed based on results of the PLS model and back propagation network with one hidden layer. The input layer was used for reflectance spectra and the output layer was for

Table 2. Results of PLS model for milling ratio of rice by reflectance.

Math treatment	Preprocess	Number of factors	Calibration		Validation		
			R^2	*SEC*	R^2	*SEP*	Bias
None	None	8	0.971	0.556	0.981	0.529	–0.063
	MSC	4	0.970	0.564	0.976	0.365	–0.145
	SNVD	7	0.964	0.621	0.973	0.620	–0.016
1st derivative (gap = 4)	None	5	0.972	0.547	0.976	0.604	–0.132
	MSC	5	0.970	0.572	0.975	0.596	–0.029
	SNVD	5	0.966	0.603	0.974	0.606	–0.028
2nd derivative (gap = 20)	None	6	0.971	0.558	0.974	0.607	–0.010
	MSC	5	0.964	0.625	0.971	0.642	–0.014
	SNVD	13	0.972	0.553	0.972	0.636	0.043

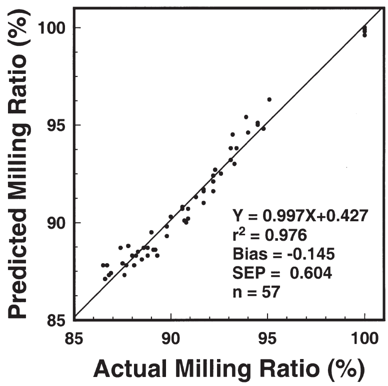

Figure 2. Comparison of actual and predicted values of milling ratio by PLS reflectance model.

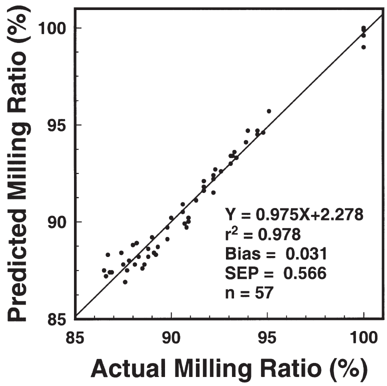

Figure 3. Comparison of actual and predicted values of milling ratio by ANN reflectance model.

Table 3. Results of ANN model for milling ratio of rice by reflectance.

Math treatment	Preprocess	Calibration		Validation		
		R^2	*SEC*	R^2	*SEP*	Bias
None	MSC	0.979	0.454	0.980	0.535	– 0.154
1st derivative	None	0.997	0.143	0.978	0.566	0.031

Table 4. The best results of models for milling ratio of rice by reflectance.

Model	Math treatment	Preprocess	Calibration		Validation		
			R^2	*SEC*	R^2	*SEP*	Bias
MLR	1st derivative	None	0.984	0.416	0.980	0.535	– 0.069
PLS	None	MSC	0.970	0.564	0.976	0.604	– 0.145
ANN	2nd derivative	None	0.997	0.143	0.978	0.566	0.031
	2nd derivative	None	0.990	0.307	0.973	0.626	0.051

milling ratios of rice. The ANN model, using the first derivative reflectance spectra without preprocessing, showed the best performance as shown in Table 3. The R^2 was 0.978 and *SEP* was 0.566%. Figure 3 shows the relationship between measured milling ratios and predicted milling ratios with the ANN model. The ANN model, using raw transmittance spectra without preprocessing, had 0.968 R^2 and 0.672% *SEP*.

Table 4 shows the performance results of the MLR model, the PLS model and the ANN model. The MLR model and the ANN model showed good results to predict the milling ratio of rice when the first derivative reflectance spectra were used without preprocessing. It seems that raw, or the first derivative, spectra were useful in developing the models because the milling ratio was a physical property of rice. The MSC preprocessing was applied in the PLS model to minimise noise and light scatter differences among samples. The ANN model showed good results during calibration and the MLR model showed the best performance for predicting the milling ratio of rice during validation.

Conclusion

The MLR model, the PLS model and the ANN model were developed to predict the milling ratio of bulk rice by visible and NIR spectroscopic techniques. 149 rice samples were used to measure both reflectance and transmittance spectra. The reflectance spectra in the range 400–2498 nm and the transmittance spectra in the range 400–1398 nm were analysed for model development. The first and the second derivatives of raw spectra were also used to develop the models with proper smoothing gap. 92 spectra were used for the calibration set and 57 spectra for the validation set.

The models using reflectance spectra showed better results than those using transmittance spectra. The MLR model, using the first derivative reflectance spectra, showed the best results for predicting the milling ratio of rice. The wavelengths selected for MLR model were 404, 1184, 1216, 1732, 1734 and 1864 nm from the first derivative spectra with 4 nm smoothing size and 8 nm of gap. The MLR model had 0.980 R^2 and 0.535% *SEP*. The PLS model using raw spectra with MSC preprocessing had 0.976 R^2 and 0.604% *SEP*. The ANN model was developed based on results of the PLS model. The ANN model, using the first derivative spectra without preprocessing, showed the good correlation between reflectance spectra and milling ratio of rice. R^2 was 0.978 and *SEP* was 0.566%.

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