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Classification of Germinatable Mung Bean by Near Infrared Hyperspectral Imaging

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Abstract**—**Hard seeds will not grow and can cause mold in sprouting process. Thus, the hard seeds need to be separated from the normal seeds. Near infrared hyperspectral imaging in a range of 900 to 1700 nm was implemented to develop a model by partial least squares discriminant analysis to discriminate the hard seeds from the normal seeds. The orientation of the seeds was also studied to compare the performance of the models. The model based on hilum-up orientation achieved the best result giving the coefficient of determination of 0.98, and root mean square error of prediction of 0.07 with classification accuracy was equal to 100%.

Keywords**—**Mung bean, near infrared, germinatability, hard seed.

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I. INTRODUCTION

THE mung bean in form of sprouts is an important ingredient in several foods for consumption in Thailand because of its high nutritional and medicinal value, which is improved by sprouts resulting from germination [1]. In the process of sprouting and seed production, hard seeds pose a major problem as they are un-germinatable in the sprouting process and they will not grow since they are impervious to water. The moist hard seeds which do not undergo sprouting will grow mold and infect neighboring sprouting seeds in the process. Thus, it is important to separate hard seeds from the normal ones. Currently, the available method for the separation of hard seeds from normal ones is the use of a reciprocating force on a sieve plate. The inclined and reciprocating movement causes the hard seeds to move on the sieve at different distance from the sound ones and thus separation. The accuracy of this method relies on the difference in the densities of the hard seeds and normal seeds, which makes this technique not very effective.

Near-infrared spectroscopy (NIRS) is regarded as an increasingly popular technique for non-destructive evaluation of internal quality of agricultural products. NIRS has been extensively utilized to assess the internal quality of mung bean. In one breeding program of mung bean, NIRS reflectance spectra were acquired from intact grains and used to develop models for prediction of palmitic, linoleic, and total fatty acid contents with success and reliable accuracy [2]. In addition, for seed conservation program, NIRS has been applied to determine the contents of protein, starch, and amylose in intact mung bean seeds [3].

At present, NIR hyperspectral imaging (HIS) has been rapidly recognized for its potential in offering both spectral and spatial information of the sample. NIR-HIS has also been applied for assessment of internal quality of various kernels. In one application, healthy and insect-damaged wheat kernels were successfully discriminated using a scanning range of 1000-1600 nm [4]. Another application showed that hyperspectral transmittance in the range of 750 to 1090 nm was applied to develop models to predict moisture and oil contents in single maize kernels [5]. The moisture model was reported to achieve better performance than the oil model. As NIR-HIS includes both the spatial dimension and the spectral dimension, very hard kernels with higher ratio of vitreous to floury endosperm (expressed as % of whole image) could be separated from very soft kernels [6]. Regarding mung bean, NIR-HIS within the wavelength region of 1000 to 1600 nm was investigated to detect Cowpea weevil infestation [7]. Uninfested and infested mung bean kernels were correctly identified with accuracies of more than 85% and 82%, respectively.

There have been a few reports on application of NIR-HIS to identify germinatable mung bean seeds. So, this research studied the potential of NIR-HIS for classification between normal and un-germinated mung bean with consideration of seed orientation.

II. MATERIALS AND METHODS

A. Sample Preparation

Samples from two crops of mung bean (Kamphaengsaen II variety) were picked and threshed to detach the seeds from the peels at a crop research center in Chainat province in the central region of Thailand. Subsequently, 200 seeds were attained. The mung bean samples were stored in an air-conditioned laboratory overnight at 25 °C with a relative humidity of approximately 85% to ensure temperature equilibrium of the seeds preceding measurement.

B. Image Acquisition of Single Kernels

A number of single kernels were placed in the holes of similar shape to the bean on a uniquely designed plate to stabilize the kernels while being imaged on the translation stage by the line-scan push broom HIS system (VLNIR-CL-100-N17E, SPECIM SisuCHEMA, Spectral Imaging Ltd., Oulu, Finland) as shown in Fig. 1. As the plate was moved under the camera, a number of beans were scanned to produce

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an image of 320×256 in the spectral range 900–1700 nm which was acquired with 320 pixels over the field of view (FOV). The system captured images with a spatial resolution of less than 15μm /pixel and a spectral resolution of 5 nm.

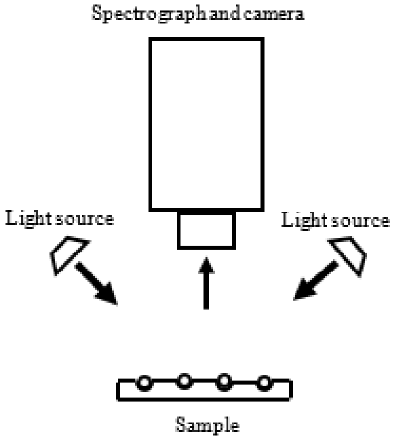

Fig. 1 Mung bean samples being scanned and imaged by HIS system

Since different orientations of the bean hilum pertaining to the light source gave different reflections for the same bean due to asymmetrical shape, each seed was scanned in three orientations with respect to the hilum of the seed. The orientations were assigned as hilum-down (HD), hilum-up (HU), and hilum-parallel-to-ground (HP) as shown in Fig. 2.

Totally 100 kernels (50 normal kernels and 50 hard kernels) were scanned.

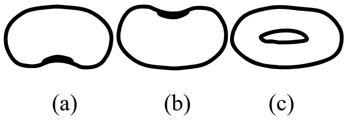
(a) (b) (c)

Fig. 2 Sample orientations (a) hilum-down, (b) hilum-up and (c) hilum-parallel-to-ground

C. Classification Model Analysis

All data analysis was carried out using MATLAB R2010a (MathWorks, Natick, MA). A classification model was developed using data from a calibration set (140 kernels) by partial least squares discriminant analysis (PLS-DA). A number of factors were determined by means of cross validation, and the performance of the model was validated on a prediction set (60 kernels). The normal kernel was assigned a value of 1 and the hard kernel a value of 0.

An improvement in the model performance was performed by pretreating the original spectra with Savitzky Golay smoothing, first derivative, second derivative, multiplicative scatter correction (MSC), standard normal variate (SNV), or a combination of them.

The effect of seed orientation was investigated by comparing the performance of HD, HU, and HP PLS-DA models.

III. RESULTS AND DISCUSSION

A. Spectral Characteristics

Fig. 3 shows the averaged reflectance spectra of normal and hard seeds.

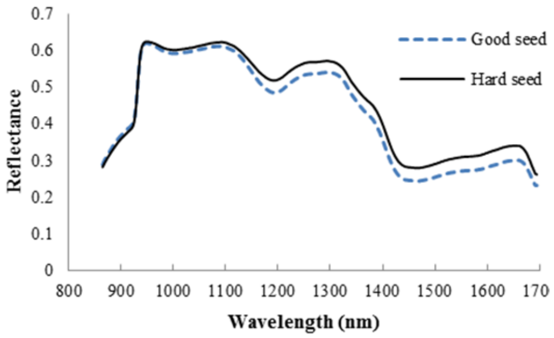

Fig. 3 The averaged spectra of normal and hard mung bean seeds

Normal seeds appeared to undergo lower light scattering and thus led to lower reflectance than hard seeds. Absorbance peaks at wavelengths around 990 and 1440 nm (Fig. 3) were associated with the presence of water. Another prominent peak at 1200 nm between the water bands was a significant starch band in association with the second overtone of C–H stretching [8]. This strong starch band verified the fact that starch was a main composition in mung bean.

B. Classification Performance

Table I presents the results obtained for the classification of normal and hard seeds. HU model based on spectra pretreated with a combination of second derivative and standard normal variate achieved the best performance in classification (R^2 = 0.98 and root mean square error of prediction (RMSEP) = 0.070). However, HP model also gave similar classification performance (R^2 = 0.98 and RMSEP = 0.075) to HU model.

For practical use of the model, the PLS-DA model based on the spectra of all orientations was required as the seed can be placed at any orientation for the measurement. The result from Table I shows that the all orientation model performed as good as the HP model with R^2 = 0.98 and RMSEP = 0.075 using SNV treated spectra.

C. Distribution Map

As hyperspectral images have the main advantage in providing both detailed spectral and spatial information, both types of information should be presented. Therefore, classification maps were produced using multivariate image analysis.

Each optimal orientation model was used to predict the state of being normal or hard seeds with values between 0 and 1 of the pixels of the prediction seeds. In the other words, each pixel was predicted for the germinatability. Fig. 4 shows some seed samples as the predicted distribution map of the germinatability.

A color scale in Fig. 4 illustrates that red color represents normal seed with good germinatability and blue color for hard seed with poor germinatability. It can be clearly visualized

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that normal seeds in the second and forth rows of Fig. 4 were represented mostly by red color, whereas some hard seeds in the first and the third rows were represented by some other colors than red color.

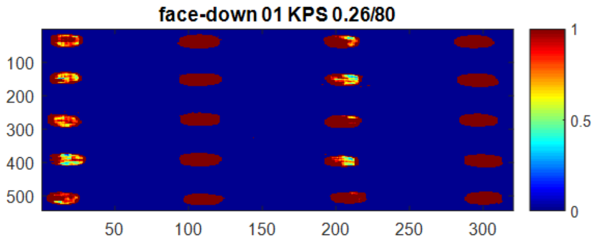
Fig. 4 shows only some samples in the analysis. However, it was noticed that, in case of hilum-up samples, the normal seeds in the second and forth rows contained mainly red color with some other colors (Fig. 4 (b)). This implied that germinatability could be determined by a ratio between red color and the other colors. The ratio for germinatable seed needed further study. Hyperspectral image had advantage over color image as hard and normal seeds could not be visually differentiated.

TABLE I
CLASSIFICATION OF NORMAL SEEDS FROM HARD SEEDS BY PLS-DA MODELS REGARDING THE EFFECT OF SEED ORIENTATION

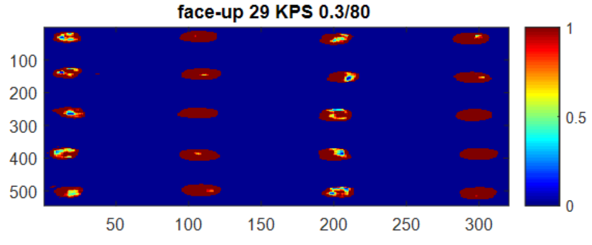
Model	Pre treatments	Number of factors	Calibration		Prediction		Correct classification (%)
			R^{2d}	RM-SECV^e	R²	RMSEP^f	
HD+HU+HP[a]	2D[b]	19	0.93	0.130	0.94	0.128	99.9
	SNV[c]	20	0.98	0.70	0.98	0.075	100
	2D+SNV	20	0.94	0.128	0.93	0.132	99.9
HD	2D	10	0.87	0.181	0.86	0.186	98.6
	SNV	10	0.92	0.145	0.90	0.157	99.5
	2D+SNV	20	0.94	0.119	0.93	0.134	99.7
HU	2D	10	0.84	0.201	0.83	0.205	98.3
	SNV	20	0.99	0.059	0.98	0.070	100
	2D+SNV	20	0.95	0.111	0.94	0.124	100
HP	2D	10	0.86	0.188	0.85	0.193	98.4
	SNV	20	0.99	0.061	0.98	0.075	100
	2D+SNV	20	0.95	0.112	0.93	0.125	100

[a] HD = Hilum-down orientation, HU = Hilum-up orientation and HP = Hilum parallel-to-the ground orientation
[b] 2D = Second derivative
[c] SNV = Standard normal variate
[d] R^2 = Coefficient of determination
[e] RMSECV = Root mean square error of cross validation
[f] RMSEP = Root mean square error of prediction

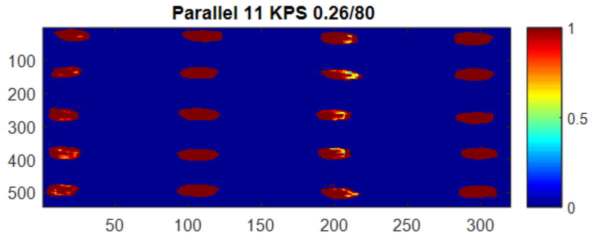
To understand the cause of distribution of the seeds, the correlation coefficient (Fig. 5) of the HU model was studied. The highest coefficient corresponded with 1200 nm wavelength. This meant the difference in starch content was partially a major cause for germination of the seeds. This was in partial agreement with a report that the seed coats of hard seeds contained 12% higher fiber content than those of normal seeds [9].



(a)



(b)



(c)

Fig. 4 Distribution maps for germinatability of hard mung bean (column 1 and 3) and normal mung bean (column 2 and 4) for (a) hilum-down, (b) hilum-up and (c) hilum parallel-to-ground orientation

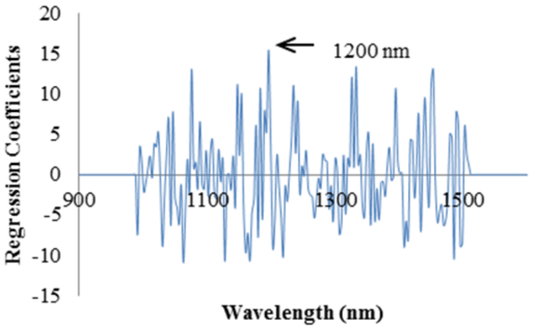


Fig. 5 Regression coefficients of the hilum-up model

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IV. CONCLUSION

The separation of hard seeds with poor germinatability from normal seeds was very important in seed production process. Application of HIS showed that normal seeds could be clearly discriminated from hard seeds using PLS-DA. The model based on hilum-up orientation spectra yielded the best performance. However, all-orientation model also achieved a good performance in classification. Distribution maps suggested that a ratio of red and other colors was a criterion in visual classification of normal and hard seeds.

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