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Eating quality evaluation of Khao Dawk Mali 105 rice using near-infrared spectroscopy

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A B S T R A C T

Eating quality evaluation of Khao Dawk Mali 105 rice (KDML105) based on near infrared spectroscopy (NIRS) of single kernels was developed to measure the amylose content of uncooked rice, and texture of cooked rice. The rice samples were scanned using near infrared transmittance spectrometry over the wavelengths of 940–2222 nm before cooking. Calibration models of amylose content and cooked rice texture were generated by partial least squares (PLS) regression based on first derivative upon logarithms of transmittance. The PLS regression for amylose content (AC) which were expressed as coefficients of determination (R^2) were 0.95 and 0.92 for calibration and prediction, respectively. Root mean square error of prediction (RMSEP) was 9.9 g/kg, dry weight. The texture of cooked rice was expressed in springiness (H1), resilience (A1), deformation (H2) and cohesiveness (A2) from low and high compression tests. The PLS prediction results (R^2_{pre}) for H1, A1, H2 and A2 were 0.61, 0.86, 0.87 and 0.91, respectively. The RMSEP (and bias) were 0.03 (0.004), 0.01 (0.001), 0.02 (0.005) and 0.01 (0.000), correspondingly. The validity of each calibration model was statistically evaluated. The use of NIRS was feasible to predict amylose content of uncooked rice, and eating quality (texture) of cooked rice before cooking.

1. Introduction

Rice (*Oryza sativa* L.) is an important crop in Thailand where it is a widely cultivated staple food that is exported worldwide. Its export volume has steadily increased since 1981, showing the rice plays an important role in Thai society and economy. Since then, the prime commodity has been ranked the top of Thailand's agricultural product. Approximately 55% of total rice produced in Thailand is domestically consumed, while the remainder is exported to world market (Vanichanont, 2004). In 2014, over 10.7 million tons of rice was shipped internationally (Thai Rice Exporters Association, 2015). Thailand's rice export market share is about 34.53% of its major trading partners, including China, Hong Kong, Malaysia, Canada, Iraq and Iran. From 1981 to 2008, Thailand was the world's leading rice exporter, shipping more than 10 billion to 200 billion tons annually over this timeframe. In Thailand, dry and flaky rice is used extensively in households for food because of its high volume expansion and low price. Soft and puffy aromatic rice is primarily exported because of its high price. Khao Dawk Mali (KDML) 105 rice, internationally known as "Jasmine Rice", is the most popular Thai rice cultivar because of its unique aroma and mild taste. Thailand is one of the world's largest producers of KDML 105 and also the world's largest rice exporter. In Thailand, KDML 105 rice is considered a vital crop for domestic consumption and a primary export commodity (Chitrakorn, 2003; Sarkarung, Somrith, & Chitrakorn, 2000). Consumer preferences for cooked rice or, the so-called eating quality rice, vary among different cultures (Juliano, 1985, pp. 443–452). Japanese people prefer short grain sticky rice, while Americans, South Americans and Middle Easterners prefer medium or long grain rice varieties that are cooked firmly and

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remain separate (non-sticky) after cooking (Lyon, Champagne, Vinyard, & Windham, 2000). Among multiple texture attributes that may affect consumer acceptability, hardness and stickiness greatly affects cooked rice eating quality (Juliano et al., 1981). The prized flavor of KDML 105 rice, which is becoming increasingly important, is collectively determined by its aroma, appearance, taste and texture. Cooked KDML 105 rice texture attributes, such as hardness and stickiness, are considered important factors in its palatability (Cameron & Wang, 2005; Champagne, Bett-Garber, McClung, & Bergman, 2004; Champagne et al., 2001; Lyon et al., 2000; Rousset, Pons, & Martin, 1999; Rousset, Pons, & Pilandon, 1995; Suwansri & Meullenet, 2004; Tomlins, Manful, Larwer, & Hammond, 2005; Yau & Huang, 1996). Cooked rice eating quality is a function of physico-chemical properties, postharvest conditions and cooking procedures (Champagne et al., 2004; Crowhurst & Creed, 2001; Daniels, Marks, Siebenmorgen, McNew, & Meullenet, 2000; Juliano & Perez, 1983; Lyon et al., 1999; Ortuño, Ros, Periago, Martínez, & López, 1996). Amylose content greatly affects the characteristics of cooked rice. It has a significant correlation with the stickiness of cooked rice (Okadome, 2005), and rice freshness (Ohno & Ohisa, 2005; Srikaeo & Panya, 2013). Ratio of stickiness to hardness is low in aged rice grains, thus the texture appeared to be hard once cooked (Ohno, Tomatsu, Toeda, & Ohisa, 2007). Multiple texture measurements of cooked rice (milled grains) were developed by Okabe (1979) with an instrument based on a three-grain method, called a texturometer. The apparatus was able to evaluate the hardness and stickiness of three cooked rice grains by causing large deformations. Okadome (2005) developed a sensitive method for measuring the texture of a single grain after cooking. This is the so-called a tensipresser apparatus (Myboy System, Taketomo Electric Inc., Tokyo, Japan). Another instrumental method that can assess rice properties, including cooked rice texture, is near-infrared spectroscopy (NIRS). This method has been used for extremely precise measurements of the chemical properties of rice, including moisture and amylose contents (Iwamoto, Suzuki, Kongseree, Uozumi, & Inatsu, 1986; Natsuga, Kawamura, & Itoh, 1992; Villareal, Cruz, & Juliano, 1994; Delwiche, Bean, Miller, Webb, & Williams, 1995; Delwiche, McKenzie, & Webb, 1996; Kawamura, Natsuga, & Itoh, 1999; Sohn, Barton, McClung, & Champagne, 2004), amylose content (Bao, Cai, & Corke, 2001; Wu & Shi, 2004; Nicolaï et al., 2007), apparent amylose content (Villareal et al., 1994), protein content (Shuso, Motoyasu, Kazuhiro, & Kazuhiko, 2003), amino acid content (Wu, Shi, & Zhang, 2002), gelatinization temperature, gel consistency (Bao et al., 2001), and rapid visco analysis (RVA) parameters (Frederick & Franklin, 2002; Siriphollakul et al., 2015). Most of the rice quality prediction models have high precision and accuracy, showing NIRS was an ideal technique for rice quality determination. NIRS has accurately predicted a variety of quality parameters in milled rice flour (Bao et al., 2001; Bean et al., 1990; Delwiche et al., 1995; Shu, Wu, Xia, Gao, & McClung, 1999a), whole grain milled rice (Delwiche et al., 1995), brown rice flour samples (Shu, Wu, Xia, Gao, & McClung, 1999b), estimated grain weight of brown rice and milled rice, and amylose content in intact single rice grains (Wu and Shi, 2004). NIRS has also been used to predict the quality of cooked rice texture from the uncooked milled rice with low to moderate success. Additionally, only limited research has been conducted on direct estimation of cooked rice eating quality (Barton, Himmelsbach, McClung, & Champagne, 2000; Windham et al., 1997). Development of instrumental techniques for assessing rice freshness and cooked rice quality can provide many useful applications to rice traders, processors, manufacturers and consumers. Based on the aforementioned literature review, it is interesting to apply NIRS to determine the physico-chemical properties of rice. Therefore, the objective of this study was to develop NIRS calibration models from single kernel rice spectra to predict amylose contents in uncooked KDML105 rice, and in the texture of various cooked rice samples.

2. Materials and methods

2.1. Raw materials

KDML 105 rice samples were obtained from the Rice Seed Center in Phanat Ni-khom District, Chonburi Province, Thailand. The rice was harvested in November, 2012. It was subsequently threshed and dried (moisture content of 110–140 g/kg) under the sun for a day prior to shipping to the Agricultural Systems Engineering Laboratory (NASER), Niigata University, Nishi-ku, Niigata Prefecture, Japan. Samples were milled using a rice miller (HS 200E, Yanmar Co., Ltd., Tokyo, Japan). The milled rice was allowed to equilibrate at 25 ± 0.8 °C for 24 h prior to NIRS measurement. The white rice was retained on a tray for obtaining head rice, i.e., kernels that retained at least 75% of their original length (USDA., 1993). Morphological characteristics (width, length and thickness) were measured using a digital caliper (SK-caliper, SK Niigata Seiki Co., Ltd., Niigata, Japan). Single rice kernels were numbered and their weights recorded. All samples were again equilibrated at 25 ± 0.8 °C in a temperature controlled tube for 24 h prior to NIRS analysis. As for sample grouping, one hundred and fifty four kernels were randomly selected for amylose content testing. While another group of 154 kernels were used for multiple texture analysis. Both groups were split into two sets of samples, namely, calibration set (100 kernels) and prediction set (54 kernels) by a sampling equipment (4 kernels a time), 25 times for calibration, and 14 times for prediction. This was done to study the feasibility of using transmission NIRS measurements to determine amylose content and predict the textural properties of cooked rice.

2.2. NIRS apparatus and measurements

A near infrared light source for transmission measurements (HR-K2150N, Hiroshi Industry Co., Ltd., Hokkaido, Japan) consisted of two 12V/100-W tungsten halogen lamps (MCR 12–150M) was used for NIRS measurements. Fig. 1 shows a schematic diagram of an NIRS apparatus for transmission measurements. Rice sample was placed in a holder which was modified from grain counting plate. The optical arrangement consisted of a black box in which an

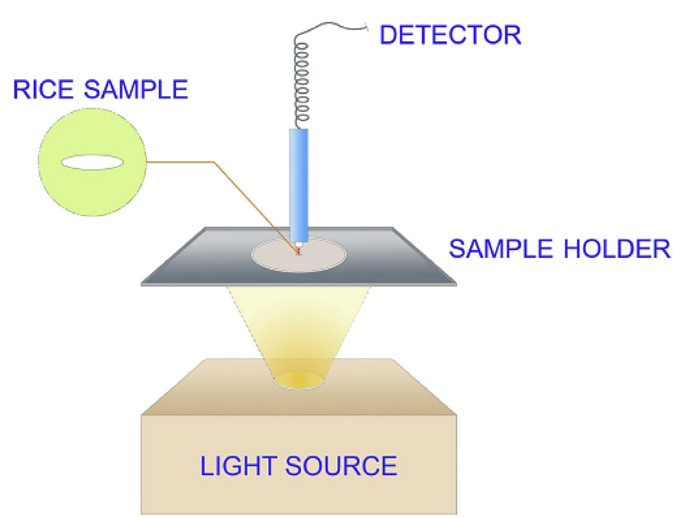

Fig. 1. Schematic diagram of near infrared spectroscopy (NIRS) apparatus for transmission measurements.

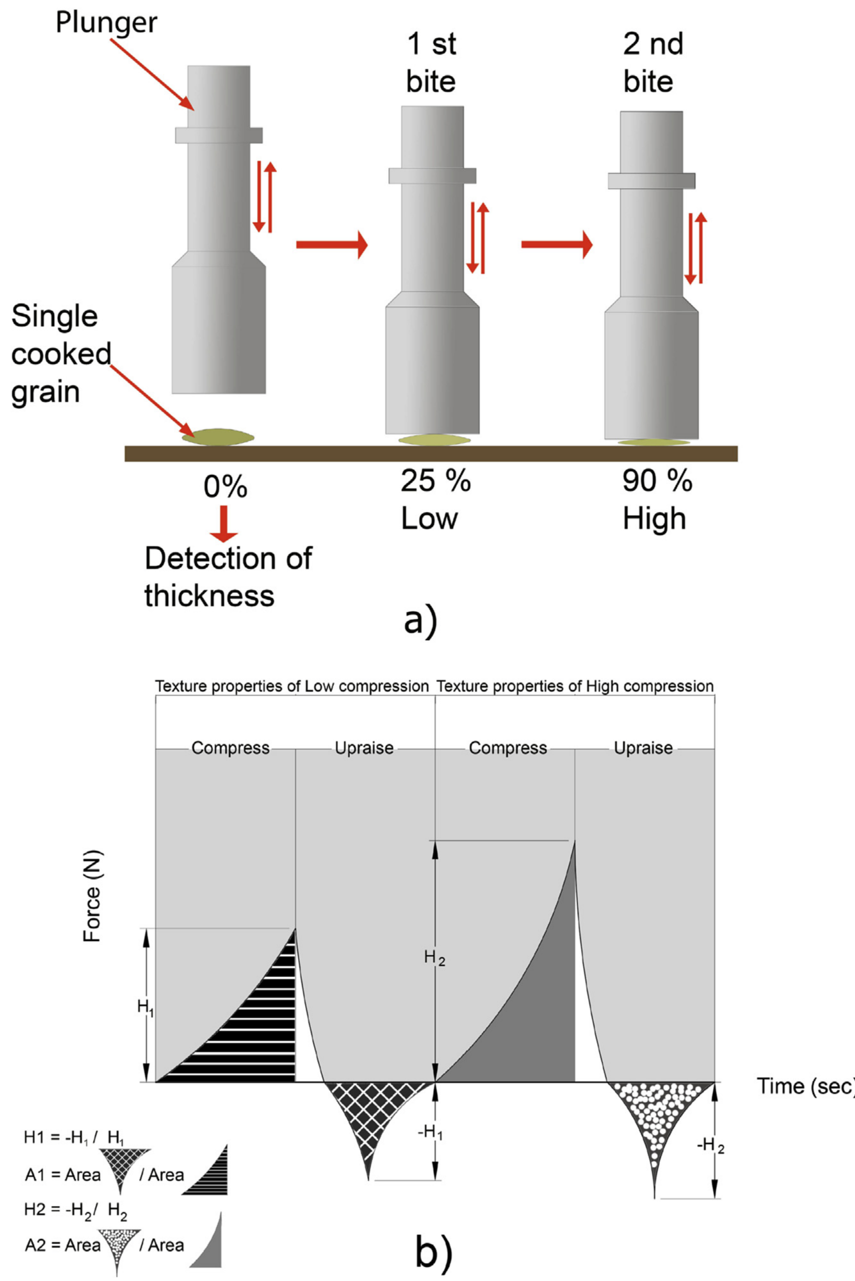

Fig. 2. (a) Low and high compression (LHC) tests of cooked milled rice grains (compression ratios for grain thickness: 25% and 90%), (b) Diagram for texture analysis from LHC tests, H1 = springiness in low compression, A1 = resilience, H2 = deformation in high compression and A2 = cohesiveness (modified from Okadome, 2005).

opposing light source and a detector fiber (diameter of 0.6 mm, made from fused quartz, and wrapped by stainless steel with silicone) were positioned. The rice sample was placed between the light source and fiber detector (2 mm from detecting probe). A white ceramic plate (thickness of 1.0 mm) was used as a reference standard for justifying the light source characteristics in transmission measurement. The light source and background were stable over the time of experiments. The NIRS measurements were made at the center of the grain by scanning 5 times using Wave Viewer software (Spectra Co., Ltd., Tokyo, Japan) prior to averaging spectra into a single NIR spectrum with Microsoft Excel. All transmitted light intensity spectra were recorded between 940 and 2222 nm with a wavelength interval of 6.6 nm using a spectrophotometer (Handy Lambda II, Spectra Co., Ltd., Tokyo, Japan).

2.3. *Traditional quality analysis*

2.3.1. *Amylose content*

After collecting near infrared (NIR) spectra, rice samples were immediately analyzed for their apparent amylose content based on the affinity of iodine for amylose using a simplified assay (colorimetric development assay) (Juliano, 1971). Amylose isolated from potato was used as a reference.

2.3.2. *Texture properties*

Texture measurements of cooked milled rice grains were obtained. One kernel of milled rice sample was added into in a test tube containing 3 ml of water. The samples were cooked using an electric rice cooker for 20 min. To avoid moisture loss after cooking, the cooked rice samples were placed into a glass chamber and

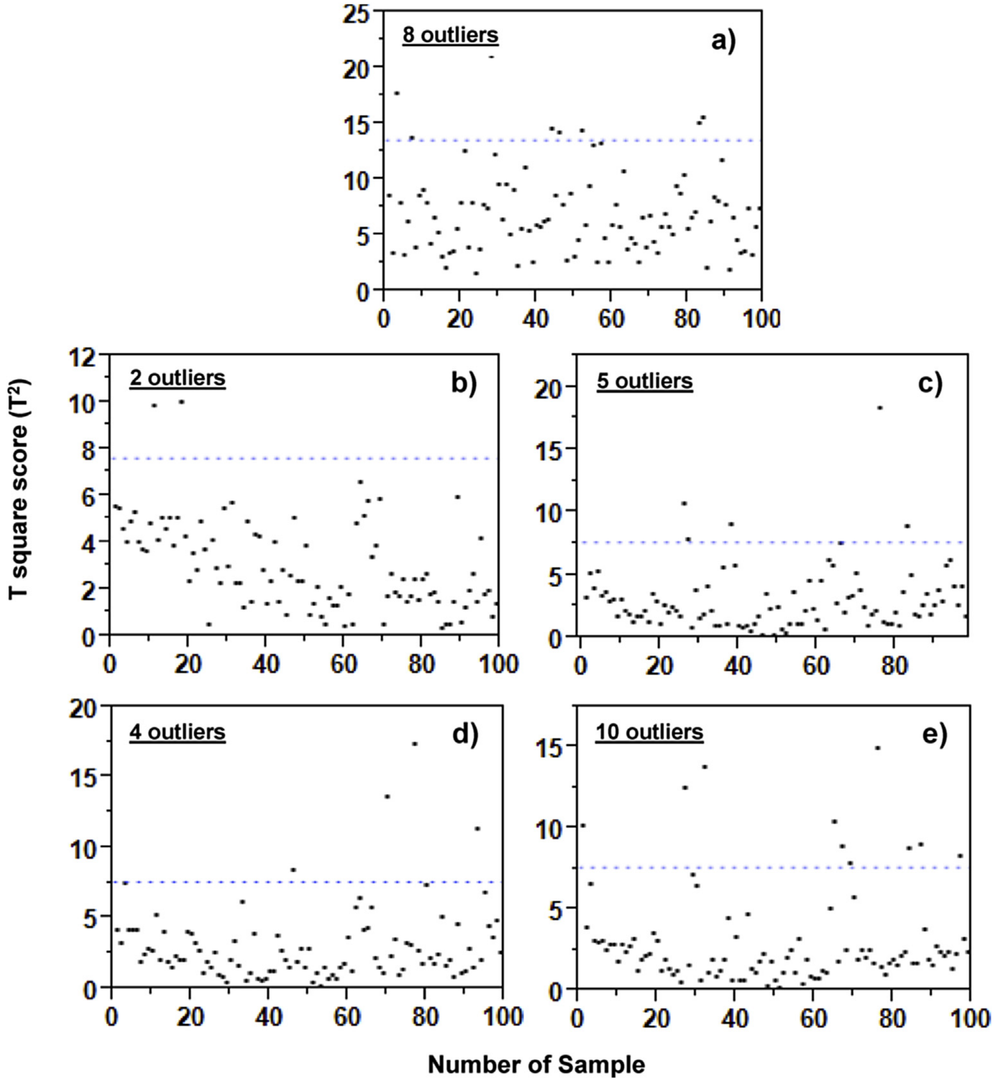

Fig. 3. T-squared scores (T^2) with control limit (blue-dotted line) of amylose content (a), springiness in low compression; H1 (b), resilience; A1 (c), deformation in high compression; H2 (d), and cohesiveness; A2 (e) in single grains of Khao Dawk Mali 105 rice (KDML 105). Samples with high residual variance during calibration that appeared above the control limit line were considered outliers. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

covered with a polyethylene film. The cooked rice was held at 25 °C for 2 min prior to conducting texture measurements. A tensipresser apparatus (Myboy System, Taketomo Electric Inc., Tokyo, Japan) was used for texture analysis of cooked rice (Okadome, 2005). The texture of cooked rice was done by low and high compression tests (LHC tests). The tests were made to enhance texture judgment as illustrated in Fig. 2. Typically, the high compression test detects the overall texture of the cooked rice kernel, while the low compression test informs information of the surface texture. The LHC tests are literally compared with the first and the second bites of eating quality. The kernel was firstly compressed by 25% of its thickness and to 90% thereafter. With this apparatus, more texture properties could be rapidly quantified. The attributes from the recorded force-time curve were analyzed on the basis of the texture profile analysis (TPA) method described by Szczesniak (1963) and Bourne (1978). In LHC tests of this experiment (Fig. 2), low compression provides ratio of springiness of cooked rice, being called H1. High compression provides information of deformation, being called H2. Samples with H2 value of 1.0 means it is fully returned to its original shape. In the meantime, when upraising the compressing plunger, two types of stickiness called resilience (A1) and cohesiveness (A2) occur upon low compression and high compression, respectively (Sirisomboon, 2011). Okadome (2005) developed low and high compression tests using a Tensipresser, where the kernel thickness was also automatically detected.

2.4. Data analysis

In this study, the spectra were expressed as the logarithm of transmittance (log(1/T)), or so-called absorbance. The first derivative pretreated absorbance (D_1log(1/T)) was determined using a Savitzky & Golay (1964) transformation and smoothing tool (7 points and second-order filtering). A multivariate method was used, i.e., partial least square regression (PLSR) analysis using JMP v.10.0 software (SAS Institute Inc., Cary, NC, USA) to develop the calibration models from NIR spectra for amylose content and multiple textures data from traditional methods. Before calibration, the reference values of outliers were identified using a T square value (T^2) with control limits (T^{cl}). Fig. 3 illustrates the samples in the calibration set with high residuals, which were considered outliers (rice grains with misshapen shape and/or internal crack, or grains with distinct physico-chemical quality). The T^2 value for the

Table 1
Morphological property of uncooked rice samples for amylose content and texture properties (N_{cal} = 100, N_{pre} = 54).

Parameters	Calibration set					
	Amylose content (100 kernels)			Texture properties (100 kernels)		
	Range	Mean	SD	Range	Mean	SD
Width (mm)	1.70–2.14	1.97	0.09	1.70–2.18	1.98	0.09
Length (mm)	6.60–7.76	7.29	0.19	6.80–8.10	7.34	0.21
Thickness (mm)	1.35–1.73	1.54	0.10	1.30–1.74	1.51	0.10
Parameters	**Prediction set**					
	Amylose content (54 kernels)			Texture properties (54 kernels)		
	Range	Mean	SD	Range	Mean	SD
Width (mm)	1.80–2.10	1.96	0.07	1.80–2.10	1.97	0.06
Length (mm)	6.66–8.10	7.31	0.15	7.05–7.70	7.39	0.18
Thickness (mm)	1.35–1.60	1.48	0.05	1.35–1.60	1.50	0.06

N_{cal} = number of kernels used in calibration set.
N_{pre} = number of kernels used in prediction set.
One kernel = one replicate.
SD = standard deviation.

Table 2
Statistical parameters for the calibration and prediction of amylose content (AC) and texture properties of cooked milled rice: springiness in low compression; H1, resilience; A1, deformation in high compression; H2, and cohesiveness; A2 in all Khao Dawk Mali 105 rice samples.

Parameters	Number of kernels	Statistical parameters		
		Range	Mean	SD
Amylose content (g/kg)	154[a]	97.00–241.70	157.30	36.80
Calibration set	100	97.00–241.70	164.00	35.80
Prediction set	54	96.90–231.30	144.90	35.80
Springiness; H1	154[a]	0.04–0.13	0.08	0.02
Calibration set	100	0.04–0.13	0.08	0.02
Prediction set	54	0.04–0.12	0.07	0.02
Resilience; A1	154[a]	0.02–0.10	0.06	0.02
Calibration set	100	0.02–0.10	0.06	0.02
Prediction set	54	0.03–0.09	0.05	0.02
Deformation; H2	154[a]	0.08–0.33	0.20	0.06
Calibration set	100	0.08–0.33	0.20	0.06
Prediction set	54	0.09–0.30	0.19	0.06
Cohesiveness; A2	154[a]	0.04–0.13	0.08	0.02
Calibration set	100	0.04–0.13	0.08	0.02
Prediction set	54	0.05–0.11	0.08	0.02

One kernel = one replicate.
[a] total samples; SD = standard deviation.

ith observation was computed as follows:

$$T_i^2 = (n-1)\sum_{j=1}^{p}\left(t_{ij}^2 \Big/ \sum_{k=1}^{n} t_{kj}^2\right) \quad (1)$$

where t_{ij} = score for the i^{th} row and j^{th} extracted factor, p = number of extracted factors, and n = number of observations used to train (leave-one-out cross validation) the model. The control limit (T^{cl}) for the T^2 plot was computed as follows:

$$T_{CL}^2 = \left((n-1)^2 \Big/ n\right)\beta(0.95, p/2, (n-p-1)/2) \quad (2)$$

where β = beta distribution, p = number of extracted factors, and n = number of observations used to train the model.

In calibration modeling, the model's prediction capability was determined using a leave-one-out cross validation and quantified by the coefficient of determination (R^2_{cal}) between predicted values from cross validation and measured values of each observation, and root mean square error of cross validation (RMSECV). The prediction results were evaluated by calculating the root mean square error of prediction (RMSEP), coefficient of determination (R^2_{pre}) between predicted values and actual values, bias and residual predictive deviation (RPD). The RPD was defined as a ratio of the standard deviation (SD) of the response variable to the RMSEP (Nicolaï et al., 2007).

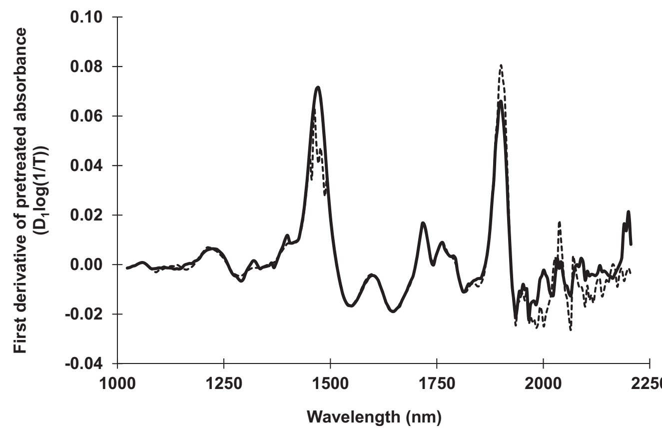

Fig. 4. Average first derivative pretreated absorbance spectra (D_1log(1/T)) of Khao Dawk Mali 105 rice grains used in amylose content determination (solid line) and texture analysis (dashed line).

3. Results and discussion

3.1. Physical, chemical and multiple texture properties of rice kernel

3.1.1. Physical properties

Morphological information of rice, i.e., diameter, width, length and thickness of 308 rice kernels are presented in Table 1. The width, length and thickness of rice varied between 1.70 and 2.18 mm, 6.60 and 8.10 mm, and 1.30 and 1.74 mm, respectively. The KDML 105 rice examined has long-grain characteristics as defined by the US world market commercial standards and the International Rice Research Institute (IRRI).

3.1.2. Physico-chemical properties and multiple texture properties

The physico-chemical properties and texture information of the rice samples are shown in Table 2. Amylose content of rice starch is the major factor contributing eating quality. KDML 105 rice was classified in the low amylose category (130–180 g/kg, dry weight) (Kongseree, 2002). In this study, our samples however had slightly greater amylose content than the reference. Since the purity of the samples was 90%, it was possible that the high amylose cultivars could contaminate in the studied samples as illustrated in Fig. 3a where outliers notably appeared during PLS modeling.

In low and high compression tests, springiness, resilience, deformation and cohesiveness showed low values: 0.08, 0.06, 0.20 and 0.08, respectively. Likewise KDML 105, Koshihikari and Aya cultivars were also considered as the low amylose containing rice as they had low values of springiness and deformation: 0.19 and 0.29, respectively. Therefore, amylose content greatly influenced cooked rice texture (Okadome, 2005). In the case of resilience (A1) and cohesiveness (A2), low values of both forces revealed that the rice kernels were unable to return to their original shape, thus, informing softness was a major character of KDML 105 cultivar.

Table 3
Calibration and prediction summaries of amylose content and texture of Khao Dawk Mali 105 rice grains from near infrared spectroscopy.

Parameters	Factors	Wavelength range (nm)	Statistical parameters					
			R^2_{cal}	R^2_{pre}	SECV	RMSECV	RMSEP	RPD
AC (g/kg)	7	940–2222	0.95	0.92	1.70	1.80	9.90	3.60
H1	3	940–2222	0.72	0.61	0.01	0.01	0.03	1.12
A1	3	940–2222	0.84	0.86	0.01	0.01	0.01	2.63
H2	3	940–2222	0.94	0.87	0.21	0.21	0.02	2.64
A2	3	940–2222	0.91	0.91	0.01	0.01	0.01	2.79

RPD = ratio of standard deviation (SD) of studied parameters in prediction set to a root mean square error of prediction (RMSEP).
AC = amylose content.
H1 = springiness in low compression.
A1 = resilience.
H2 = deformation in high compression.
A2 = cohesiveness.
R^2_{cal} = coefficient of determination for calibration.
R^2_{pre} = coefficient of determination for prediction.
SECV = standard error of cross validation.
RMSECV = root mean square error of cross validation.

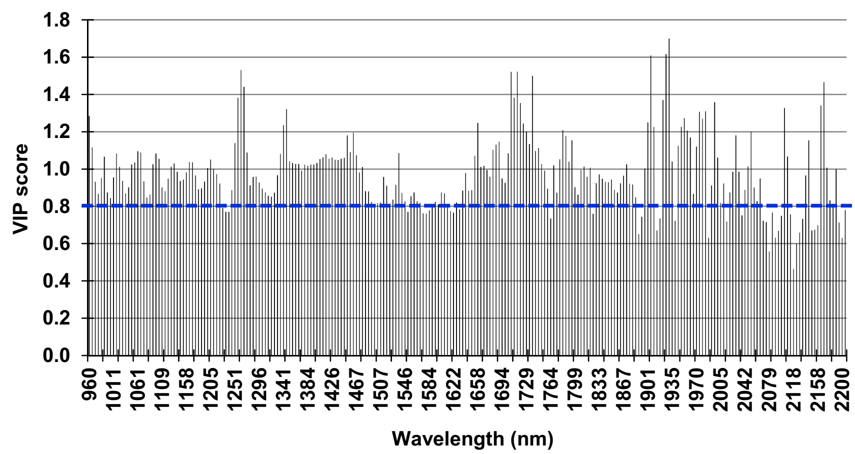

Fig. 5. Variable importance in projection (VIP) scores in amylose content modeling using partial least square (PLS) regression analysis. Variables (wavelengths) with VIP scores greater than 0.8, were considered as potential contributors for PLS modeling.

3.2. Calibration and prediction results

3.2.1. Features of NIRS spectra

Fig. 4 shows first derivative spectra of intact single KDML 105 kernels from transmission measurement for amylose content and texture analysis. Wavelengths in range of 940–2222 nm were used to develop partial least squares (PLS) calibration models. This figure reveals absorption peaks around wavelengths of 1450 nm and 1900 nm region. The peak located at 1450 nm was related to the first overtone of O-H band stretching vibration of starch and water. The peak at 1900 nm was found to be a signature of the second overtone of C=O band stretching vibration of starch ($-CO_2H$), and O-H stretching vibration + 2 × C-O stretching vibration of starch (Osborne, Fearn, & Hindle, 1993).

3.2.2. PLS models and results

An optimum number of factors used in the developed PLS models was determined by root mean predicted sum of squares or PRESS analysis. The changes of residuals were considered when applying higher factors during cross validation. The PRESS analysis from JMP software helped limit the number of variables in the case where the model contained variable redundancies resulting in a poor prediction result. For amylose content, 7 factors were elicited, while the rest of the parameters contained 3 factors in the PLS models. The leave-one-out cross validation results (R^2_{cal} of 0.72–0.95) indicated that the models were useable for prediction.

Calibration and prediction results of the developed PLS models for amylose content and texture properties of milled rice are shown in Table 3. Model performance was evaluated on the basis of coefficient of determination (R^2_{pre}) between the measured values and NIRS predicted values, RMSEP, RPD and bias. The best PLS model for amylose content prediction was obtained from the first derivative pretreated absorbance spectra ($D_1\log(1/T)$) in the NIR range of 940–2222 nm. A R^2_{pre} of 0.92 indicated relatively high model performance, thus, suitable for research routine (Osborne et al., 1993). The PLS models also provided high correlations for resilience, deformation and cohesiveness parameters, 0.86, 0.87 and 0.91, respectively. Prediction results also revealed small RMSEP, 0.01, 0.02 and 0.01, respectively, and low bias, 0.001, 0.005 and 0.000, respectively. As for RPD, PLS models provided values greater than 2.0, especially for amylose content (3.60), resilience (2.63), deformation (2.64), and cohesiveness (2.79). However, only RPD of springiness parameter appeared to be relatively low (1.12). Calibration models with calculated RPDs between 2.0 and 10.0 are considered useable and dependable for prediction (Fearn, 2002).

The NIRS calibration and prediction results for amylose content and texture properties PLS models are displayed as tabular data in Table 3. The values of RMSEP were relatively low, meaning the models could feasibly predict targeted properties of milled rice kernels. A good model should provide a high coefficient of determination (R^2) for prediction, low RMSEC (in our case, RMSECV) and RMSEP. The current study showed relatively high R^2_{pre} and low RMSECV and RMSEP values. So, the NIRS transmission measurement could accurately predict amylose content and most of the texture properties of KDML105 rice. Similar nondestructive studies of rice quality prediction were carried out during the past two decades, such as amylose estimation in brown rice and white rice (Villareal et al., 1994), starch determination in short-, middle-, and long-grain rice (Delwiche et al.,1995; Bao et al., 2001), quality characteristics of rice grain and flour (Delwiche et al., 1996; Sohn et al., 2004), and physico-chemical quality of intact rice grain (Kawamura, Natsuga, & Itoh, 1999; Wu & Shi, 2004).

The results in Table 3 also indicated that reasonable models ($R^2_{pre} > 0.70$) were obtained from the use of wavelengths between 940 and 2222 nm. This region typically has high molecular absorptivity. The variable importance in projection (VIP) score, a weighted sum of squares of the regression weights, is a value that summarizes the contribution a variable makes to the PLS model. The clear peak revealed sensitive wavelengths around 1900 nm for amylose regression modeling (Fig. 5). Osborne et al. (1993) reported that starch and amylose are typically sensitive to wavelengths of 1900 nm and 2100 nm. Both compounds are found as major components of rice.

4. Conclusion

Eating quality of KDML105 rice was nondestructively determined by near infrared spectroscopy (940–2222 nm) using a single kernel transmission measurement. Precise amount of amylose content in uncooked rice was predicted by partial least square regression analysis with low prediction error. Wavelength of 1900 was a key variable for amylose content predictive regression. Cooked rice texture (resilience, deformation and cohesiveness parameters) was also feasibly predicted, expressing softness character and easily-deformed shape of KDML 105 rice. Therefore, near infrared spectroscopy was an effective analytical tool for determination of eating quality of cooked rice prior to cooking.

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