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Eating quality of cooked rice determination using Fourier transform near infrared spectroscopy

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The goal of this research was to study the relationship between the eating quality of cooked rice and near infrared spectra measured by a Fourier Transform near infrared (FT–NIR) Spectrometer. Samples of milled: parboiled rice, white rice, new Jasmine rice (harvested in 2012) and aged Jasmine rice (harvested in 2006 or during the period 2007–2011) were used in this study. The eating quality of the cooked rice, i.e., adhesiveness, hardness, dryness, whiteness and aroma, were evaluated by trained sensory panelists. FT–NIR spectroscopy models for predicting the eating quality of cooked rice were established using the partial least squares regression. Among the eating quality, the stickiness model indicated its highest prediction ability (i.e., $R^2_{\text{val}} = 0.71$; RMSEP = 0.65; Bias = 0.00; RPD = 1.87) and SEP/SD of 2. In addition, it was clear that the water content did not affect the eating quality of cooked rice, rather the main chemical component implicated was starch.

Keywords: Rice; FT–NIR spectroscopy; eating quality.

1. Introduction

Rice (*Oryza sativa* L) is one of the principle foods consumed by human around the world especially in Asia. Important rice products include milled rice and parboiled rice. Parboiled rice is unprocessed rice that has undergone partial steaming. In contrast, milled rice is produced by removing the husk, bran layer and the germ.

Consumer appreciation of rice depends upon the quality of the cooked rice product. The determination of the eating quality of cooked rice is closely monitored by the rice processing and milling

industry. During the rice production process sampling is conducted to determine the six key eating quality attributes: adhesiveness, hardness, dryness, stickiness, aroma and whiteness. At present the eating quality of samples are determined using a descriptive analytical sensory analysis by trained human panelists. Unfortunately, sensory based analysis methods are slow, complex and lead to the destruction of the test objects. Therefore, a novel analytical method that is fast, easy and non-destructive for evaluating eating quality of rice is highly sought after within the rice processing industry.

Near infrared (NIR) spectroscopy is a non-destructive method that has been applied to evaluate a variety of properties of agricultural products and foods. NIR spectroscopy is efficient because it dramatically reduces the time needed for experimental analysis, thereby leading to lower overall costs. Researchers have studied the application of NIR spectroscopy to analyze the amylose content, protein content, and lipid content of rice, with satisfactory outcomes.[1–4] Researchers also reported the use of NIR spectroscopy to predict the sensory characteristics of foods such as virgin olive oil,[5] apple,[6] table grape,[7] lamb meat[8] and beef steaks.[9]

In recent years, methods relying on Fourier transform near-infrared (FT–NIR) spectroscopy have been developed to overcome limitations associated with the NIR spectroscopic instrument. FT–NIR records the intensity of absorbance across the entire spectrum as a function of the optical path differences (OPD) between two NIR beams in an interferometer.[10] The two beams are created by splitting the measurement beam, i.e., the beam that is transmitted through or reflected from the specimen.[10] One split beam travels over a different optical path length, via a moving mirror, and is recombined with the second beam to create an interference signal.[10] The total interference signal results from the mirror traveling through a range of wavelengths and is transformed to spectral components via a fast Fourier transform.[10] The FT–NIR spectrometer has a number of advantages over the conventional grating NIR spectrometer including; (1) higher signal to-noise ratios, (2) extremely high resolutions and (3) fast and accurate frequency determinations.[11] FT–NIR spectroscopy was successfully applied to analyze properties of rice such as the lipid content of milled rice (long, medium and short grains)[12] and the optimal cooking time of rice.[13] However, to date FT–NIR spectroscopy has not been used to evaluate the eating quality of rice where the reference method was the sensory approach.

The goal of this research was to study the relationship between the eating quality of cooked rice and its near infrared spectral data measured using an FT–NIR spectrometer. The results from this FT–NIR spectroscopy study could prove useful in real world applications associated with the rice processing and marketing.

2. Materials and Methods

2.1. *Determination of criteria of eating quality indices*

Samples of five different types of milled rice, which cover the full of eating quality range, were prepared by the quality control section of a rice processing plant (C.P. Rice Co., Ltd., Thailand) and delivered to the Near Infrared Spectroscopy Research Center for Agricultural Product and Food at King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand. In this research, we assess the principal eating quality indices of rice which encompass adhesiveness, hardness, stickiness, dryness, whiteness and aroma, all of which have been used by the rice quality processing plant.

The five types of the rice samples were cooked according to the water to rice ratios suggested by the processing plant. A team of panelists consisting of five males and five females were each served with the five types of cooked rice. The panelists were allowed to confer among one another before collectively deciding on the score to give to each of the samples. The scoring system for adhesiveness, hardness, dryness and stickiness are on a scale from 1 to 5, where 1 denotes the maximum level and 5 the lowest level. For aroma and whiteness, the scoring is reversed, where 1 represents the lowest level while 5 represents the maximum level. All scores provided by panelists were integers only (i.e., 1, 2, 3, 4 or 5).

2.2. *The training of sensory panelists*

The 10-member panelists were firstly trained using multiple training sessions to acquaint themselves with the scoring criteria needed to perform the rice

sensory evaluation in a consistent fashion. Each panelist was served with a scoop of cooked rice of five different types. Upon being served with the cooked rice, the panelists first smelled the samples so as to perform the aromatic assessment. The panelists were trained to assess the cooked rice adhesiveness by either shaking a portion in a small closed-lid plastic container or by gently scraping the top surface of the rice samples with a small plastic spoon, or both. For hardness and stickiness, the panelists were asked to chew all the five types of cooked rice and summarize their conclusions using concise words and scores related to their hardness (e.g., extremely hard (1), hard (2), etc.) and stickiness (e.g., extremely sticky (1), sticky (2), etc.). The panelists were also trained to determine sample dryness by visually observing the moistness of the cooked rice. Whiteness was visually assessed. These eating quality criteria were then used in the subsequent scoring of the samples in the experimental stage.

The sensory evaluation of each of the five rice types were performed in duplicate. The training session continued until the 10 participating panelists were skilled at the quality assessment process. It should be noted that before each assessment, the panelists would be served with drinking water to wash out the aftertaste and rice residues from the previous assessment. Note the cooked rice samples in the training sessions were of different lots from those used in the main experimental stage.

2.3. *Rice samples*

The 250 samples of milled rice were received from the same rice quality improvement plant. The rice samples were randomly garnered from three locations inside the plant premises, i.e., from the raw material receiving station, behind the color sorter machine, and under the storage bin. These three locations were selected for sample collection since they are the sites at which rice samples are typically collected for the internal quality inspection. The samples of milled rice were of parboiled rice, white rice, new Jasmine rice (harvested in 2012) and aged Jasmine rice (harvested in 2006 or during 2007–2011). A total of 51, 23, 12 and 164 samples of each variety were selected, respectively. The weight of each milled rice sample was approximately 200 g, which was stored in a plastic zipper bag until the experimental analyses were performed.

2.4. *Cooked rice preparation*

Home electronic rice cookers (RC-10 MM, Toshiba, Thailand) were used to cook 250 samples of five types of milled rice, each weighing 200 g. The five rice types were cooked according to the different water to rice ratios recommended by the plant, i.e., 2.5:1 for parboiled rice; 1.6:1 for white rice; 1:1 for new Jasmine rice harvested in 2012 and 1.2:1 and 1.4:1 respectively for aged Jasmine rice harvested in 2007–2011 and in 2006. The rice was considered fully cooked once the rice cooker automatically switched to the warm mode. The cooked rice was gently but thoroughly mixed using a plastic ladle before transferring to the small closed-lid plastic containers for sensory evaluation. The cooked rice samples were then presented to the sensory panelists for evaluation.

2.5. *Sample scanning*

Each cooked rice sample was scooped into a Petri dish with the following dimensions (53.5 mm diameter and 15 mm height). Three replicates were assessed per sample. The NIR spectrum of the cooked rice samples were measured using an FT–NIR spectrometer (MPA, Bruker Ltd., Germany) in reflection mode between 12,500–4000 cm^{-1} (800–2500 nm) at a resolution of 8 cm^{-1}. An average spectrum for each sample was obtained from 64 separate scans recorded in absorption mode ($\log 1/R$).

2.6. *Sensory evaluation*

The trained sensory panelists of five males and five females were asked to separately score each sample on a scale of 1–5 for all six eating quality indices. As discussed previously, 5 denotes the minimum level and 1 the maximum level, for adhesiveness, hardness, dryness and stickiness. This scale is reversed for the whiteness and aroma.

The scores of the eating quality indices given by the panelists were allowed to contain only one decimal point. The evaluation of the 250 cooked rice samples followed the same procedures established during the training stage. Each sample was assigned a three-digit random number. About 8–10 samples were served to the panelist at a time. Moreover, after each sample evaluation, the panelists were served with drinking water to wash out any aftertaste or rice residue remaining from the previous assessment. Prior to each sensory evaluation day,

the panelists were re-trained on the sensory evaluation criteria to ensure evaluation consistency.

2.7. *Spectrum pre-treatment and NIR spectroscopy model establishment*

The NIR spectroscopy models for predicting the eating quality of cooked rice were established using partial least squares regression (PLS). The multivariate analysis software (OPUS, v. 7.0, Bruker, Germany) was used in both spectrum preprocessing and model creation. About 80% of the experimental samples (i.e., 601 samples of 750 analyzed) were used in the calibration group while the remainder (149 samples) was placed in the validation group. The calibration group was used for the model creation. The model error was then calculated using the full cross-validation method. The same model was then used to predict the samples in the validation group. The optimum wavenumber range and preprocessing method were selected using the default optimization procedures of the software. The predictive capability of the models were assessed using the coefficient of determination of the calibration and validation groups (R^2_{cal} and R^2_{val}, respectively), root mean square error of estimation (RMSEE), root mean square error of prediction (RMSEP), bias, and ratio of standard deviation of validation data to RMSEP (RPD).

2.8. *Overall precision test*

The overall precision or reproducibility was assessed by conducting tests on 27 pairs of blind duplicates from the experiments on the 750 samples. The reproducibility is defined as the standard deviation (SD) of the differences between the values of the blind duplicates. In addition, another 18 rice samples were selected as a new set of duplicates (27 pairs) to determine the repeatability of the reference tests. This is defined as the SD of the differences between the values of these duplicates. The ratio of standard error of prediction (SEP) to the SD from the reproducibility test, SEP/SD, was then computed to evaluate the predictive capability of all the calibration models, where SEP/SD < 1.0 represents an excellent NIR calibration model; SEP/SD $= 1.0$ to 2.1 a good NIR calibration model; SEP/SD $= 2.1$ to 2.4 a fair NIR calibration model; SEP/SD $= 2.5$ to 3.0 a poor NIR calibration model and SEP/SD > 3.0 an unreliable NIR calibration model (Tony, Pietroutonio, Caltest, USA, personal communication).

3. Result and Discussion

3.1. *NIR spectroscopy model*

The mean, SD, maximum (Max), and minimum (Min) values of the eating quality of cooked rice for calibration and validation groups are shown in Table 1. The range of stickiness values was widest, i.e., 1.0 to 5.0., whereas the hardness range was narrowest, 1.3 to 4.7. The range of adhesiveness was equal to those of aroma, and whiteness (1.0 to 4.8), while the dryness range was between 1.2 and 4.7. The eating quality has an SD of validation between 1.09 and 1.23. The SD of adhesiveness and stickiness was highest at 1.23.

The prediction statistics for the PLS models to predict the eating quality of cooked rice are shown in Table 2. The optimum model for the prediction of adhesiveness was established from the raw spectra. The max–min normalization method led to the most predictive models for the prediction of hardness and stickiness. The models for dryness were derived from the spectra preprocessed using the first

Table 1. Minimum (Min), maximum (Max), mean, and SD of the six eating quality indices associated with cooked rice for the calibration and validation groups.

	Calibration					Prediction				
Parameter	Number of samples	Min	Max	Average	SD	Number of samples	Min	Max	Average	SD
Adhesiveness	601	1.0	4.8	2.4	1.10	149	1.0	4.8	3.0	1.23
Hardness	601	1.3	4.7	3.5	0.98	149	1.3	4.6	3.0	1.09
Dryness	601	1.2	4.7	3.5	0.98	149	1.2	4.5	3.0	1.11
Stickiness	601	1.0	5.0	2.5	1.08	149	1.0	5.0	3.1	1.23
Aroma	601	1.0	4.8	3.7	0.98	149	1.0	4.7	3.2	1.16
Whiteness	601	1.2	5.0	3.7	1.01	149	1.2	4.8	3.1	1.21

Table 2. Statistics of prediction for the eating quality indices of cooked rice by PLS models.

Parameter	Pre-treatment	Wavenumber range (cm^{-1})	PC	R^2_{cal}	R^2_{val}	RMSEE	RMSEP	BIAS	RPD
Adhesiveness	Raw spectra	9403.8–7498.3, 6102–5446.3, 4605.4–4242.9	8	0.71	0.69	0.60	0.68	0.07	1.82
Hardness	Min–max normalization	9403.8–7498.3, 6102–4242.9	8	0.69	0.69	0.55	0.60	−0.01	1.80
Dryness	First derivative + Straight line subtraction	9403.8–7498.3, 6102–4597.7	8	0.69	0.68	0.55	0.62	−0.05	1.78
Stickiness	Min-max normalization	9403.8–7498.3, 6102–4597.7	8	0.71	0.71	0.59	0.65	0.00	1.87
Aroma	MSC	9403.8–4597.7	5	0.65	0.67	0.59	0.67	0.02	1.74
Whiteness	Vector normalization	8454.9–7498.3, 6012–4597.7	4	0.63	0.65	0.62	0.72	−0.06	1.69

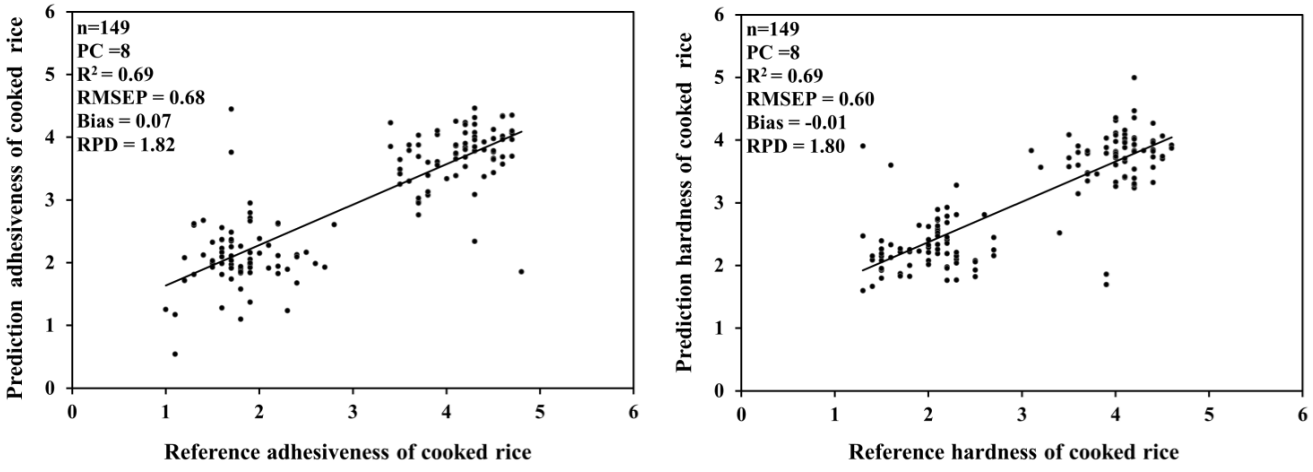
PC — Optimal number of principal components,
R^2_{cal} — The coefficient of determination of calibration set,
R^2_{val} — The coefficient of determination of validation set,
RMSEE — Root mean square error of calibration,
RMSEP — Root mean square error of prediction, and
RPD — Ratio of SD of validation data to RMSEP.

derivative and straight line subtraction method. The models for the prediction of aroma and whiteness were created using spectra preprocessed using the multiplicative scattering correction (MSC) and vector normalization methods, respectively.

The prediction results of all eating quality indices showed R^2_{val} values between 0.65 and 0.71. The results for stickiness displayed the highest predictive capability of all the eating quality indices (i.e., $R^2_{val} = 0.71$; RMSEP = 0.65; Bias = 0.00; RPD = 1.87). The R^2_{val} values for adhesiveness and hardness, indicative of texture properties of cooked rice, were both 0.69. The dryness and whiteness parameters, both of which are evaluated visually, showed R^2_{val} values of 0.68 and 0.65, respectively. The aroma based models exhibited an R^2_{val} of 0.67.

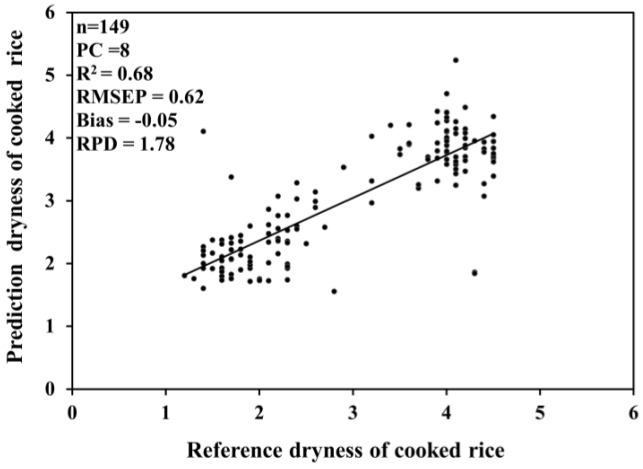
The scatter plots (reference data (X) with prediction data (Y)) of each of the eating quality indices are shown in Fig. 1. The regression coefficient plots of the optimum models for evaluating the eating quality of cooked rice are shown in Fig. 2.

The regression coefficient plots for the eating quality models do not show absorption bands associated with water (13,158, 10,309, 6897 and 5155 cm^{-1}).[14] It was clear that the water content was not closely related to the eating quality of cooked rice. The regression coefficient plots of all eating quality indices show peaks around 8840–8655 cm^{-1}

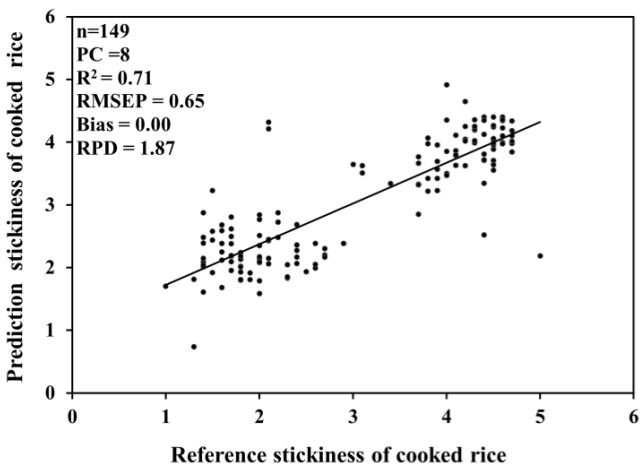


(a) (b)

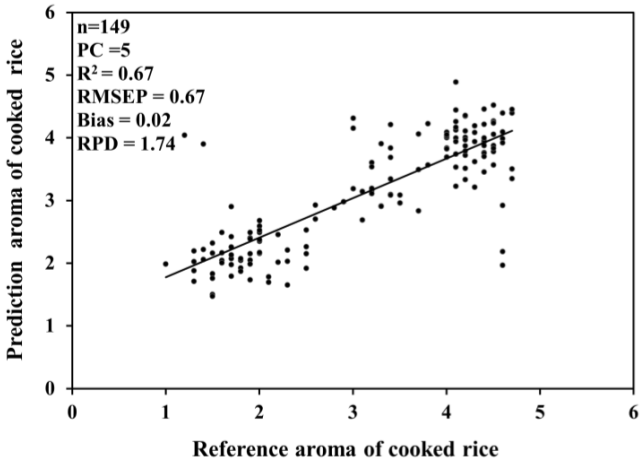
Fig. 1. Scatter plots of the reference data (X) against the prediction data (Y) for the six eating quality indices associated with cooked rice. These are: (a) Adhesiveness; (b) Hardness; (c) Dryness; (d) Stickiness; (e) Aroma and (f) Whiteness.



(c)



(d)



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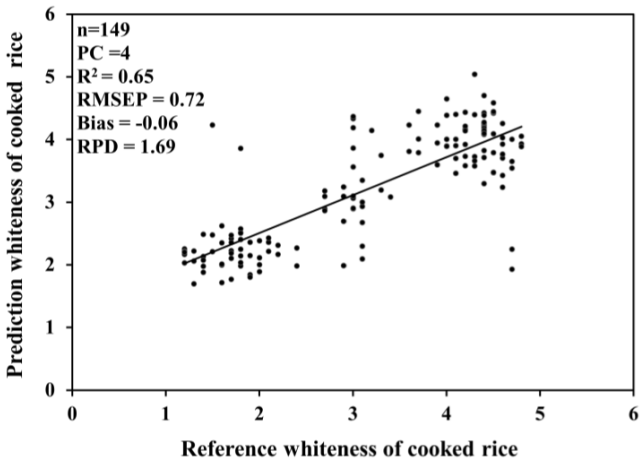
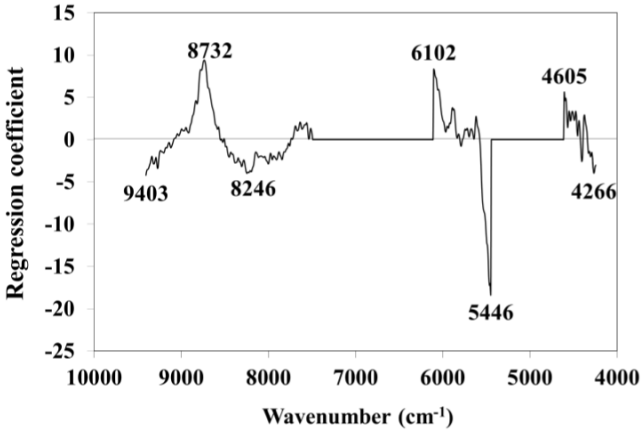
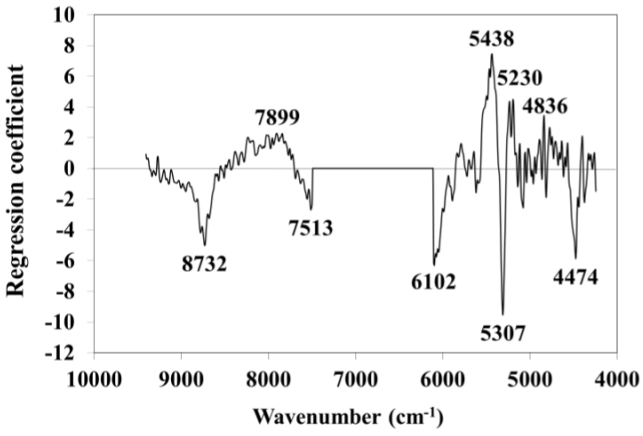


(f)

Fig. 1. (*Continued*)



(a)



(b)

Fig. 2. Regression coefficient plots for the optimal PLS models associated with the six eating quality indices of cooked rice. (a) Adhesiveness; (b) Hardness; (c) Dryness; (d) Stickiness; (e) Aroma and (f) Whiteness.

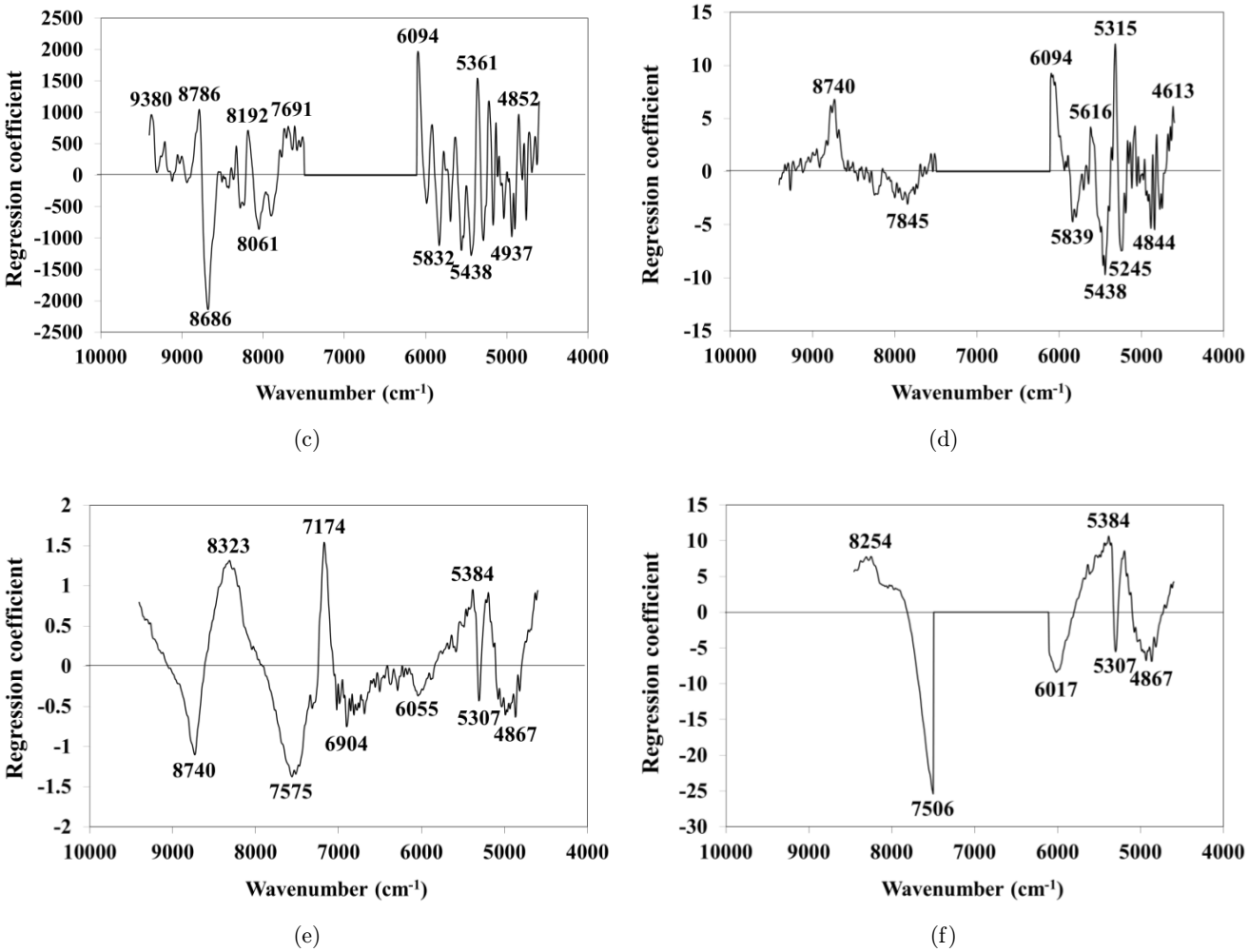


Fig. 2. (*Continued*)

(1131–1155 nm). The prominent features around 8840–8655 cm^{-1} are the absorption peaks associated with the first overtone of C–H stretching of the starch (i.e., 8841–8658 cm^{-1} or 1131–1155 nm).[15] It is perhaps obvious that carbohydrates are the main chemical component of rice that affects the eating quality. Table 3 shows means and standard deviations (SD) of the differences between the duplicates and ratios of standard error of prediction (SEP) to standard deviation (i.e., SEP/SD) of the overall precision tests. The SD values of the tests are the indication of precision of sensory panelist on evaluation of eating quality of cooked rice. The repeatability of all eating quality indices was less than 0.3 and the reproducibility was between 0.2–0.3 except for whiteness (0.5) which was 4–6% of maximum value (5). This indicated that the evaluation by panelist was fairly precise. The ratios of SEP/SD of reproducibility tests imply the performance of NIR spectroscopy model for practical application. The SEP/SD values of stickiness and whiteness model was 2 indicated that the model was good. The values for models of adhesiveness, hardness and dryness were 3 indicated the poor

Table 3. Means, SDs and ratios of SEP to SD (i.e., SEP/SD) for duplicate measurements (i.e., repeatability and reproducibility tests).

		Repeatability test		Reproducibility test		
Quality	SEP	Mean	SD	Mean	SD	SEP/SD
Adhesiveness	0.68	−0.1	0.2	0	0.2	3
Hardness	0.65	0	0.3	−0.1	0.2	3
Dryness	0.67	0.1	0.2	−0.1	0.2	3
Stickiness	0.70	0	0.2	0.1	0.3	2
Aroma	0.71	−0.2	0.2	0.2	0.2	4
Whiteness	0.75	−0.1	0.2	0	0.5	2

SEP — Standard error of prediction.

performance of the models. The model for aroma could not be recommended because the SEP/SD was 4.

4. Conclusion

Predictive models for rice quality have been generated using input from FT–NIR spectroscopy. Models for stickiness and whiteness showed the highest predictive performance ($R^2_{val} = 0.71$ and 0.65; RMSEP = 0.65 and 0.72 and; Bias = 0.00 and −0.06; RPD = 1.87 and 1.69, respectively) and SEP/SD of 2 and 2. This indicated that FT–NIR spectroscopic methods applied to cooked rice could be used to evaluate certain eating quality indices of cooked rice (i.e., stickiness and whiteness). In addition, it was clear that the water content of the rice samples was not related to the eating quality of the cooked rice. However, it was clearly apparent that starch as the main chemical component of rice, was the dominant factor.

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