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Social Science Journal

Non-destructive prediction of pineapple fruit firmness using NIR-HIS

By

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Abstract

Texture, and particularly firmness, is an important and commonly used indicator of internal quality and ripeness of fruit. An objective method of measuring firmness would be beneficial in achieving quality control and reducing costs in fruit marketing, especially for export. Reflectance near infrared hyperspectral imaging (NIR-HSI) has been used as a nondestructive method for this purpose and was tested on predicting the firmness of pineapples. The spectral data, using NIR-HSI, and firmness, using a texture analyzer, were tested on 120 pineapples in order to develop a calibration model using partial least squares regression (PLSR). Samples were divided into a calibration set (N = 80) and a prediction set (N = 40) for establishing and testing the model, using the best method from spectral pretreatments was by multiplicative scatter correction (MSC). The accuracy of the model had R_p and RMSEP of 0.77 and 0.15 kg_f, respectively indicating that there was good correlation between NIR-HSI and texture analyzer measurement showing that the model could be used for screening intact pineapples for firmness nondestructively.

Index Terms— absorbance, model, spectrum, fruit, calibration

Introduction

Pineapples are a major commodity and are marketed in various forms including juice, frozen, ready-to-eat, canned and as fresh fruit. World production of pineapples were 26.1, 27.7, 28.4 and 28.2 million tonnes per annum over the period 2016, 2017, 2018 and 2019 respectively. Exports of fresh pineapples were 3.7, 3.8, 4.0 and 3.9 million tonnes per annum over the period 2016, 2017, 2018 and 2019 respectively [1]. In 2019, the main producers of pineapples were: Costa Rica, Philippines, Brazil, Indonesia, China, India and Thailand. Quality of pineapples is very important for both the fresh market and processing industry. Firmness is an important property that is used as an indicator of their quality.

Textural properties of fruit are related to both flesh and skin and vary depending on tissue composition, physical stresses and geometrical surface of fruit. Textural properties of fruit can be perceived and estimated by a combination of tactile, visual and hearing senses and its determination is complex and can be influenced by consumer preference as well as assessment methods and the instruments used [2]. Firmness is a critical attributes that consumers use for determining quality of fresh fruit and vegetables [3] and is usually determined using a destructive method. But a method for determining firmness, accurately, quickly and non-destructive would be of immense benefit to the vegetable, fruit, and food based industries.

Near infrared (NIR) spectroscopy is a nondestructive techniques that has been applied in online grading systems [4]. NIR radiation covers a range of electromagnetic spectrum between the wavelength of 780 nm and 2,500 nm. NIR spectra for biological products occur from absorptions of the vibration energy that interacts with molecular groups of C-H, O-H and N-H chemical bonds [5].

Hyperspectral imaging (HSI) is an integration of spectroscopy and imaging techniques in order to obtain spectral and spatial information [6] .HSI provides the spectral spatial information that facilitates the development of models for detect several compounds, diseases and defects in agricultural products [7]. HSI is a useful technique because it enables fast analysis, has little or no labor involvement, low operating cost and environmental benefits [8]. NIR-HSI has been successfully used in many kinds of food and agricultural products including: ham [9], rice [10], corn kernels [11], wheat [12], apples [13], oranges [14], cake [15], eggs [16], limes [17] and tapioca starch [18]. No research has been previously reported on the use of NIR-HSI for assessing firmness of pineapples. Therefore, this objective of this research was to study the possibility of NIR-HSI for use in predicting the firmness of pineapples non-destructively.

Material and Mathods

Sample preparation

Pineapples [Ananas comosus (L.) Merr.] cv. 'Pattawia', of Thai commercial grade and of similar size were bought from local market in Bangkok. Samples were stored in an air conditioning room at 25°C about 24 hr before scanning with NIR-HSI.

NIR-HSI measurement

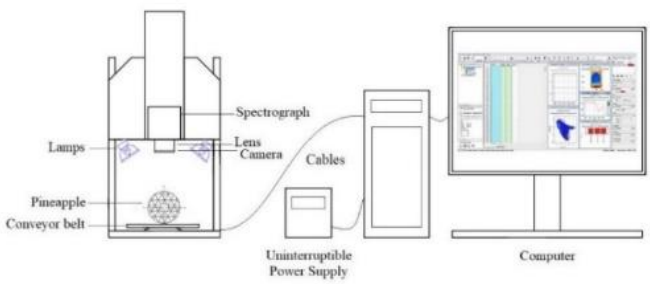

Fig 1. *Sample presentation and NIR- HSI system*

Each fruit sample was placed in a horizontal position and moved on the conveyor belt through the camera's field at a speed of 15.00 mm/s. Six halogen lamps were used as the light source during scanning. Each sample was scanned in reflectance mode using a push-broom-laboratory-based CHEMA system and a hyperspectral camera (Specim Fx17, Spectral Imaging Ltd, Oulu, Finland) in the wavelength of 935-1720 nm. A dark reference and a white reference were measured at each scanning. The dark image was acquired when a shutter and a camera were closed while the white image was acquired by scanning a Spectralon reference (Fig. 1).

Firmness measurement

Firmness of each pineapple was measured at the position of bottom, middle and top of the fruit on the same side as that scanned by NIR-HSI using a TA-TX2 Texture Analyzer (Stable Micro Systems Ltd. Surrey, England) with a 2 mm diameter cylindrical stainless probe (P/2), test speed 10 mm/s and penetration depth of 5 mm [2]. Average firmness was calculated and used for analysis.

Model establishment

A common method for spectral analysis that is used to establish the model is partial least-squares (PLS) regression that can effectively be used for the variable multiplicity with dimension reduction for regression analysis [19]. The selection of the principal component number affects the accuracy of the PLSR model, therefore the root-mean-square error was utilized for selecting the optimal principal component number [20] .Spectral pretreatment techniques including Savitzky-Golay smoothing, Savitzky-Golay first derivative differentiation, Savitzky-Golay second derivative differentiation, multiplicative scatter correction and standard normal variate transformation were used and each technique was combined and investigated using correlation coefficient of cross-validation (R_{cv}) and root mean square error of cross validation (RMSECV). This was done in order to obtain the optimal condition for establishing the PLSR model. The predictive capabilities of the PLSR model were evaluated using correlation coefficients (R_c, R_p) and root mean square error (RMSEC, RMSEP). The data were analyzed using Microsoft Office Excel (Microsoft, USA), the Unscrambler X Version 10.5.1 (CAMO, Osla, Norway) and the UmBrio Evince hyperspectral image analysis software (Prediktera Evince, version 2.7.5, Sweden).

Result and Discussion

Spectra of pineapple

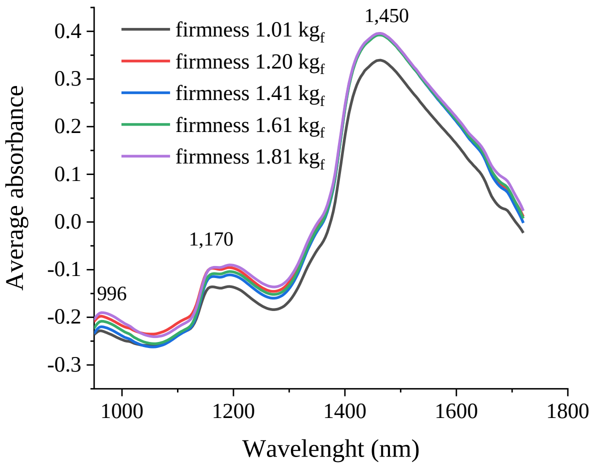

Fig. 2. *Average spectra of pineapple fruit of different firmness*

Spectra of each fruit from the region of interest (ROI), that is the whole intact fruit. Were averaged and used for analysis. For comparing spectra based on firmness, fruit were grouped into 5 groups according to their firmness: group 1.0 -0.8) 1 kg_f: average 1.01 kg_f(, group 1.2-1.1) 2 kg_f: average 1.20 kg_f(, group 1.4-1.3) 3 kg_f :average 1.41 kg_f(, group -1.5) 4 1.6 kg_f: average 1.61 kg_f(, and group 1.9-1.7) 5kg_f :average 1.81 kg_f) .The average absorbance spectra of each fruit, in the wavelength range of 935-1,720 nm were differed depending on its firmness (Fig. 2). Pineapples that had higher NIR absorbance had higher firmness. Normally, the original absorbance spectra of the pineapple fruit showed combined peaks of its components. In Fig. 2 the peaks showed at around 996, 1,170 and 1,450 nm on the spectra. This effect could be because the NIR absorbance of the fruit was related to components that affected their firmness such as cellulose and fiber, with the peaks of cellulose at 996 nm and 1,450 nm associated with the third overtone of O-H and the second overtone of O-H, respectively. The peak of fiber as lignin, at 1,170 nm, was associated was associated with the third overtone of C-H [21].

PLSR model establishment

To develop the PLSR model, the dependent variables were firmness values and the independent variables were absorbance spectra at the wavelength range of 935-1,720 nm. The pineapples samples (N=120) were divided into two sets with 80 fruits used for the calibration set and 40 for the prediction set (Table 1). The calibration set had a larger number of samples (66.7%) and the range of firmness was covered by those in the prediction set. The distribution of firmness in both sets was similar.

Table 1 *Characteristics of firmness in the calibration set and the prediction set*

Items	N	Range (kg_f)	Average (kg_f)	S.D (kg_f)
Calibration	80	0.87-1.98	1.48	0.25
Prediction	40	0.99-1.92	1.44	0.24

N= number of samples, S.D = standard deviation

The spectral data of pineapples in the calibration set were preprocessed using spectral pretreatment methods described above. The results showed that the MSC had the highest R_{cv} and the lowest RMSECV of 0.749, 0.165 kg_f, respectively (Table 2). Therefore, multiplicative scattering collection (MSC) was used as a preprocessing tool to correct the light scattering problems in the NIR spectra [22]. MSC absorbance spectra were adjusted and the feature was changed (Fig. 3). The spectral pretreatment using MSC was the most effective for creating the model, therefore it was used for analysis in this study

Table 2 *Results of PLSR model by spectral pretreatment methods in the calibration set at the wavelength range of 935-1,720 nm*

Pre-treatment techniques	Firmness (kg_f)		
	PC	R_{cv}	RMSECV (kg_f)
Original	6	0.737	0.168
Smoothing	6	0.746	0.165
1st Derivative	4	0.714	0.174
2nd Derivative	5	0.616	0.199
MSC	**6**	**0.749**	**0.165**
SNV	5	0.747	0.165
Smoothing + 1st Derivative	4	0.743	0.166

PC = the number of principal components from partial least squares regression, R_{cv} = correlation coefficient of cross-validation, RMSECV = root mean square error of cross validation, Smoothing = Savitzky-Golay smoothing, 1st derivative = Savitzky-Golay first derivative differentiation, 2nd derivative = Savitzky-Golay second derivative differentiation, MSC = multiplicative scatter correction and SNV = standard normal variate transformation.

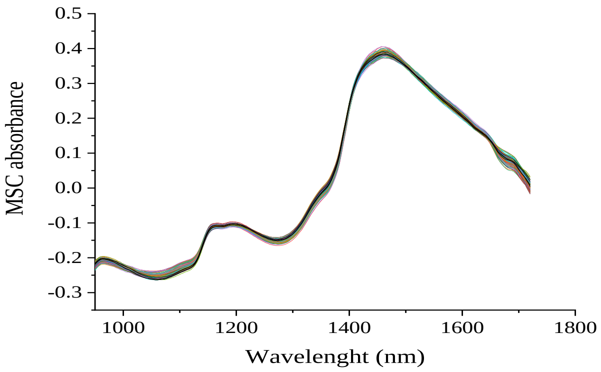

Fig. 3. *Spectral pretreatment by MSC*

PLSR model performance

The PLSR model was tested on the samples in the calibration set (R = 0.81 and RMSE = 0.14 kg_f) and the samples in the prediction set (R = 0.77 and RMSE = 0.15 kg_f). The results showed that the performance of the PLSR model for predicting firmness of pineapple was accepted to use for rough screening (Table 3) [23].

Table 3 *The result of the model predicting the firmness of pineapple*

Items	N	PC	R	RMSE (kg_f)
Calibration	80	6	0.81	0.14
Prediction	40	6	0.77	0.15

N= number of samples, PC = the number of principal components from partial least squares regression, R = correlation coefficient, RMSE = root mean square error

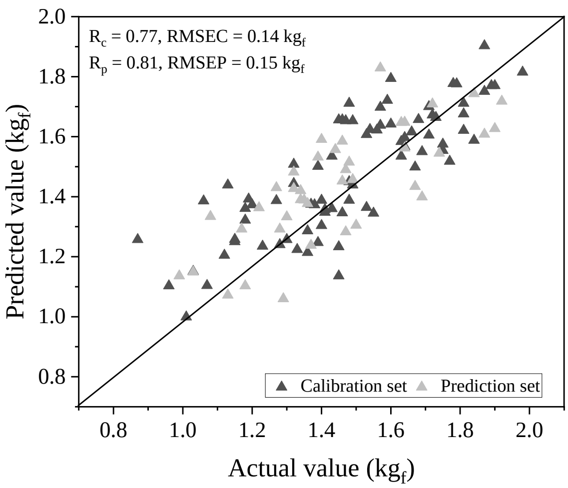

Fig.4. *Scatter plot of predicted firmness and actual firmness of samples in the calibration set and the prediction set using the PLSR model*

The distribution of the data between predicted firmness and actual firmness of samples in the calibration set and the prediction set by PLSR model were agglomerated along the 45° line (Fig.4). The results of the PLSR model for firmness obtained R = 0.81 for calibration and R = 0.77 for prediction, which showed that the model had a preliminary level of accuracy [24].

Conclusion

Near infrared hyperspectral imaging, in the wavelength range 1 -935, 720nm, was shown to be a possible method that could be used for predicting firmness of pineapple fruit. Also, multiplicative scatter correction was successfully used for the spectral pretreatment in order to establish the PLSR model. It was concluded that near infrared hyperspectral imaging could be a possible tool for use in pineapple fruit marketing and processing for predicting their firmness non-destructively, but further research is needed.

Acknowledgment

The authors wish to gratefully acknowledge the financial support from the King Mongkut's Institute of Technology Ladkrabang (KREF016324) and This research was funded by National Research Council of Thailand (NRCT) In addition, The authors are grateful Prof. Panmanas Sirisomboon for technical help.

Refferences

FAO, Major Tropical Fruits Market Review February, 2020.

Marta Montero-Calderon, M.A.R.-G.a.O.M.-B., "Mechanical and chemical properties of Gold cultivar pineapple flesh (Ananas comosus)". Zeitschrift für Lebensmittel-Untersuchung und -Forschung. A, European food research and technology. 230(4): p. 675-686, 2010.

Sirisomboon, P., M. Tanaka, and T. Kojima, "Evaluation of tomato textural mechanical properties". Journal of Food Engineering. 111(4): p. 618-624, 2012.

Alfatni, M.S.M., et al., "The application of internal grading system technologies for agricultural products – Review". Journal of Food Engineering. 116(3): p. 703-725, 2013.

Nicolaï, B.M., et al., Chapter 13 - Non-Destructive Evaluation: Detection of External and Internal Attributes Frequently Associated with Quality and Damage, in Postharvest Handling (Third Edition), W.J. Florkowski, et al., Editors. 2014, Academic Press: San Diego. p. 363-385.

Wu, D. and D.-W. Sun, "Advanced applications of hyperspectral imaging technology for food quality and safety analysis and assessment: A review — Part I: Fundamentals". Innovative Food Science & Emerging Technologies. 19: p. 1-14, 2013.

Dale, L.M., et al., "Hyperspectral Imaging Applications in Agriculture and Agro-Food Product Quality and Safety Control: A Review". Applied Spectroscopy Reviews. 48(2): p. 142-159, 2013.

Roggo, Y., et al., "A review of near infrared spectroscopy and chemometrics in pharmaceutical technologies". Journal of Pharmaceutical and Biomedical Analysis. 44(3): p. 683-700, 2007.

Iqbal, A., D.-W. Sun, and P. Allen, "Prediction of moisture, color and pH in cooked, pre-sliced turkey hams by NIR hyperspectral imaging system". Journal of Food Engineering. 117(1): p. 42-51, 2013.

Wang, L., et al., "Use of Hyperspectral Imaging to Discriminate the Variety and Quality of Rice". Food Analytical Methods. 8(2): p. 515-523, 2015.

Kandpal, L.M., et al., "Short wave infrared (SWIR) hyperspectral imaging technique for examination of aflatoxin B1 (AFB1) on corn kernels". Food Control. 51: p. 171-176, 2015.

Verdú, S., et al., "Detection of adulterations with different grains in wheat products based on the hyperspectral image technique: The specific cases of flour and bread". Food Control. 62: p. 373-380, 2016.

Lan, W., et al., "A method using near infrared hyperspectral imaging to highlight the internal quality of apple fruit slices". Postharvest Biology and Technology. 175: p. 111497, 2021.
Riccioli, C., D. Pérez-Marín, and A. Garrido-Varo, "Optimizing spatial data reduction in hyperspectral imaging for the prediction of quality parameters in intact oranges". Postharvest Biology and Technology. 176: p. 111504, 2021.
Sricharoonratana, M., A.K. Thompson, and S. Teerachaichayut, "Use of near infrared hyperspectral imaging as a nondestructive method of determining and classifying shelf life of cakes". LWT. 136: p. 110369, 2021.
Suktanarak, S. and T. Sontisuk, "Non-destructive quality assessment of hens' eggs using hyperspectral images". Journal of food engineering. 215: p. 97-103, 2017.
Teerachaichayut, S. and H.T. Ho, "Non-destructive prediction of total soluble solids, titratable acidity and maturity index of limes by near infrared hyperspectral imaging". Postharvest Biology and Technology. 133: p. 20-25, 2017.
Khamsopha, D., S. Woranitta, and S. Teerachaichayut, "Utilizing near infrared hyperspectral imaging for quantitatively predicting adulteration in tapioca starch". Food Control. 123: p. 107781, 2021.
Wold, S., M. Sjöström, and L. Eriksson, "PLS-regression: a basic tool of chemometrics". Chemometrics and Intelligent Laboratory Systems. 58(2): p. 109-130, 2001.
Wang, C., et al., "Dynamic monitoring oxidation process of nut oils through Raman technology combined with PLSR and RF-PLSR model". LWT. 146: p. 111290, 2021.
Workman, J. and L. Weyer, "Practical Guide and Spectral Atlas for Interpretive Near-Infrared". CRC, 2012.
Yukihiro Ozaki, S.T., Christian Huck and Søren Balling Engelsen, "Near-Infrared Spectroscopy Theory, Spectral Analysis, Instrumentation, and Applications". 2021.
Williams, P., "Near-Infrared Technology Getting the Best Out of Light Edition 5.0. A Short Course in the Practical Implementation of Near-infrared Spectroscopy for the User". Nanaimo, Canada: PDK Grain, 2007a.
Williams, P., "Near-infrared Technology-Getting the Best out of Light". Canada: PDK project Inc., 2007.