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The Use of VIS/NIR Hyper-Spectral Analysis on Moisture and Fat Content Predictions for Breaded-Fried Chicken Nuggets

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Abstract: Moisture and fat contents are two important parameters in quality evaluation of fried chicken nuggets. This study was undertaken to evaluate moisture and fat contents of fried breaded chicken nuggets using VIS/NIR hyper-spectroscopic technique. Breaded nugget samples were fried for different times in hydrogenated canola oil in order to obtain various levels of moisture and fat contents. Reflectance spectra of samples were collected within the range of 400-1750 nm using a spectroradiometer. Partial Least Squares (PLS) calibration models were developed for quantitative evaluation of the two parameters. The R^2 and Root Mean Square Error (RMSE) for each prediction were calculated to assess the prediction capability of the model. R^2 values of 0.92 were obtained from cross-validation of calibration for total moisture and fat contents. Validation of the calibration resulted in RMSE of 0.105 for moisture content and 0.017 for fat content predictions. VIS/NIR spectral analysis was proved to be a straightforward and fast method for prediction of the two important quality parameters of fried breaded chicken nuggets (moisture and fat) and once the calibration model was developed, the VIS/NIR instrument was capable of doing the analysis in few minutes.

Key words: Deep-fat frying, partial least squares method, multivariate statistical analysis

INTRODUCTION

Deep-fat frying is considered as one of the most common food preparation operations in the world. Among various types of fried food products, breaded foods are favored by consumers because of their unique textural properties provided by a soft and moist core coated with a crispy crust, along with more desirable color, flavor and nutritive value[1].

During frying, simultaneous heat and mass transfer within and around the food causes various complex physical and chemical changes[2]. Water is transferred from the food into the frying oil, while the oil is absorbed as a replacement. Due to health concerns and consumers' increasing demands for reduced-fat foods, oil content of fried food has become an important factor in determining quality of fried food. It is also desirable to minimize moisture loss from fried food during frying in order to maintain textural characteristics of the final fried product[3]. It has been reported that the rates of moisture loss and fat uptake depended on the conditions of frying process such as frying temperature and time. Higher frying temperature was found to lead to a faster moisture loss rate[4]. At higher temperatures, a faster crust formation leads to a higher fat absorption for the same frying time[5]. However, higher frying temperature requires reduced frying time resulting in lower final fat content of the product[6]. The ratio of food weight and frying oil volume also affects the amount of fat absorption[5]. Therefore, in order to optimize the frying process and to improve the quality of fried food, a fast and reliable method for determination of moisture and fat contents of the fried products is needed.

Moisture and fat contents are traditionally measured using the oven-drying and solvent extraction methods[7] with tedious and long procedures. Near-Infrared Spectroscopy (NIRS) as an alternative to those time-consuming and destructive traditional methods enables fast and simultaneous measurements of several parameters and has potentials in on-line food analysis. In contrast with chemical methods, NIRS eliminates the use of hazardous solvents and reagents[8]. Successful applications of VIS/NIR spectroscopy for analysis of water and fat contents in food have been reported in the past two decades. Togersen *et al.*[9] developed an on-line NIR spectroscopic technique for prediction of chemical composition of semi-frozen ground beef such as moisture and fat. Alomar *et al.*[10] investigated the prediction ability of NIRS for chemical compositions of raw beef meats. Anderson and Walker[1] also studied the

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application of on-line VIS/NIR spectroscopy to determine the fat content in ground beef stream and reported a high accuracy with Standard Error of Prediction (SEP) of 1.00-1.68% for calibration and 2.15-2.28% for validation.

The goals of this study were to investigate the potentials of VIS/NIR reflectance spectroscopy for determination of moisture and fat contents in fried breaded chicken nuggets; to develop calibration models with the highest precision and reliability for determination of moisture and fat contents; to select the best wavelength bands to predict fat and moisture contents and to test and validate the calibration models' performances on moisture and fat contents prediction. The results can lead to a successful design of an on-line quality assessment technique for chicken nugget products.

MATERIALS AND METHODS

Sample preparation: Frozen breaded chicken nuggets were obtained from a local supermarket and kept frozen at -18°C until being used. Chicken nuggets with similar size and shape were selected as test samples for the experiment. The average weight of samples was 21.3 g. Frozen chicken nugget samples were thawed at room temperature (22°C) for 30 min before frying.

Chicken nugget samples were deeply fried in hydrogenated canola oil using a domestic fryer at 180±2°C. A temperature controller (model 689000-01, Eutech instrument Pte Ltd., Singapore) was connected to the fryer to control the frying temperature. Fresh oil was preheated for 2 h before frying the samples. The chicken nugget samples were fried one by one to minimize temperature fluctuation during frying. In order to obtain different levels of moisture and fat contents, the chicken nugget samples were fried for 1, 2, 3 and 6 mins. The frying times were used as the basis for grouping the samples. Smaller intervals (1 min) between 3 and 6 min did not lead to statistically significant changes in fat and moisture contents and were eliminated from the collected data. This trend of change was similar to the results reported by other researchers with similar experimental procedures[11,12]. Twelve samples were collected at each frying time. The fried samples were cooled down to room temperature before spectral measurement. Spectral reflectance of all the samples was recorded. Six samples were then randomly selected and grouped for the measurement of moisture and fat contents of the crust part of the chicken nugget namely, crust moisture and crust fat content. The remaining 6 samples were grouped to be used to measure moisture and fat contents of the whole chicken nugget namely, total moisture and total fat content.

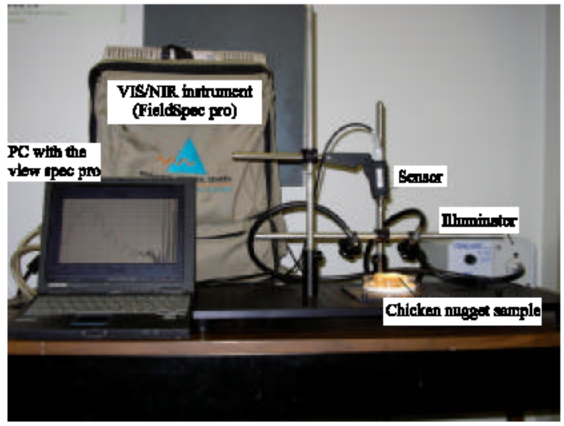

Fig. 1: Experimental set up for spectral data collections

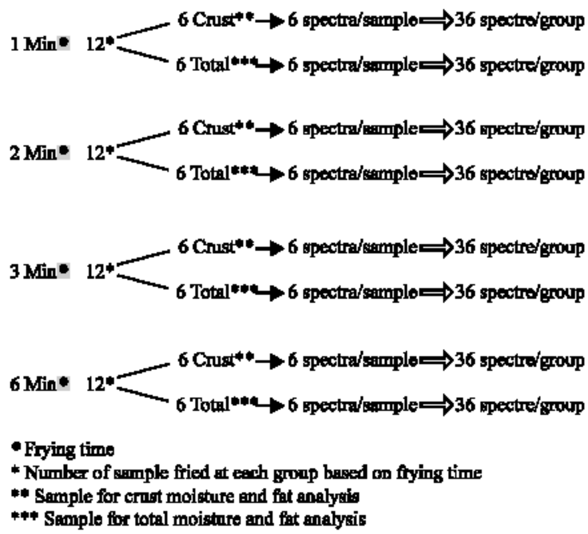

Fig. 2: Procedure of grouping the samples and the corresponding spectra based on the frying time.

Spectral collection: Hyper-spectral reflectance data was acquired using a portable hyper-spectroradiometer (FieldSpec® Pro, Analytical spectral devices, Boulder, Colorado, USA) with a resolution of 3 nm in a range of 400-1750 nm. A fried chicken nugget sample was placed at a fixed distance of 10 cm underneath the detector of the spectroradiometer Fig. 1. The distance was determined based on the field of view of the detector (18°) and the size of the samples. A DC regulated fiber-optic illuminator (Fiber-Lite PL900-A, Dolan-Jenner Industries Inc, MA, USA) was used as a light source. Two fiber-optic light-guiding branches were mounted on a test frame to guide light to the sample. From each sample, three spectral reflectance readings were collected at three different spots of the front side and three other readings from the back side of the sample. Therefore, for each sample, six spectra were collected. Data acquisition process was controlled by the ViewSpec Pro software (Analytical spectral devices, Boulder, Colorado, USA) and the collected spectra were stored for further analysis. Spectral data were grouped based on the frying time, including 36 spectra in each group obtained from six samples. Figure 2 shows the procedures of grouping the samples and the corresponding spectra.

After spectral data collection, the crust portions of the samples that were assigned for crust analysis were separated for determination of crust moisture and crust fat. For the rest of the samples, assigned for overall analysis, the moisture and fat content of the whole chicken nugget was measured. A hypothesis was established and tested that the moisture and fat contents of the crust portion maybe correlated with the moisture and fat contents of the total sample. Thus, it allows the prediction of total moisture and fat contents based on the spectral readings.

Chemical tests: Moisture content: Moisture content was determined using the freeze drying method. Initial mass of fried samples was measured by an electric scale (TR-4102D, Denver Instrument Co., Denver, CO). Drying process was conducted in a freeze dryer (ModulyOD-115, Thermo Savant, Holbrook, NY) at -50°C for 36 h. Final mass of dried samples was measured and moisture content was calculated by difference in weight and reported on dry basis. Dried samples were then kept in a desiccator for further fat analysis.

Fat content: Fat content was determined using AOAC solvent extraction method 991.39[7]. Portions of 2-5g of ground sample were weighed with the electronic scale (TR-4102D) and placed in a thimble for the instrumental extraction. The fat content of the samples was extracted using a Solvent Extractor (SER 148, Velp Scientifica, Usmate, Italy) with petroleum ether as the solvent. At the end of the operation, the remaining solvent in the extracted fat was removed in a conventional oven (Isotemp 700, Fisher Scientific, Pittsburg, PA) at 125°C for 30 min. The weight of extracted fat was determined and fat content of samples were calculated by the following formula and reported on dry basis. Fat content on dry basis was calculated as the ratio of the mass of extracted fat and the mass of dried sample.

The mean moisture and fat contents and the Standard Deviation (SD) in each group of the samples were calculated and the mean values were used for VIS/NIR calibration model development. Results of chemical analyses were reported as average crust moisture, average crust fat, average total moisture and average total fat.

VIS/NIRS calibration and data analysis

Spectral analysis: Spectral analysis was performed using the GRAMS/AI software (V7.02, Thermo Electron Corp., Salem, NH, USA). Four calibration models were developed. Model 1 was developed for crust moisture and fat analysis using full spectral range, while Model 2 was developed for crust analysis using feature wavelength regions. Model 3 was developed for total moisture and fat analysis using full spectral range, while Model 4 was developed for total moisture and fat analysis using feature wavelength regions. To build calibration Models 1 and 2, 30 spectra were randomly selected from the total number of 36 spectra in each group to build the training set. Since there were four groups of samples assigned for crust moisture and fat analysis, a total number of 120 spectra along with their corresponding crust moisture and fat contents were used as the training set. The remaining 24 spectra were used for validation of calibration model. This procedure was repeated to create training and validation sets for Models 3 and 4.

Partial Least-Squares (PLS) method was used to establish the calibration models along with mean-centering and automatic baseline correction as preprocessing. Two parameters, fat and moisture contents from the chemical analysis, were used as “constituent” data and the spectra were used as the “spectral” data for training sets. The PLS procedure yielded the calibration models, the optimal numbers of factors used in the calibration models, the feature wavelengths for predicting the constituents and the predicted constituents for each sample in the training set. Each calibration model was assessed by a leave-one-out cross validation and the optimal number of factors was determined by the minimum Predicted Residual Error Sum of Squares (PRESS). Outliers of the training set were detected according to the concentration residuals and eliminated from the training set. Calibration models with the highest R^2 from cross validation were chosen as the best models. Root-Mean-Square-Error (RMSE) for the validation set was calculated for each constituent to asses the precision of prediction.

PLS feature wavelength selection: For each calibration model, PLS Beta coefficient plots of each constituent (moisture and fat) were used to determine feature wavelength ranges that indicated significant variations in the reflectance spectra. Beta coefficient values are regression coefficients that show the weight of contribution of each wavelength to the calibration model. This could assist in the development of a model which, using selected regions, could predict the moisture and fat contents. Eliminating the regions with no or very less contribution to the calibration model would reduce the time for calibration calculation. Also selected wavelength regions can be used as a basis to design simplified systems with less cost for rapid determination of moisture and fat contents of fried chicken nuggets.

Multivariate regression analysis for feature wavelength selection: In order to verify the selected feature wavelength ranges from plots of beta coefficient, regression analysis of the spectral data for Models 1 and 3 was performed by the SAS software (V. 8.20, Cary, NC, USA). The reflectance values of each wavelength were used as the independent variable whereas moisture and fat content values were used as dependent variables. The regression analysis was aimed to find feature wavelengths at which the independent variable (reflectance value) contributed to the most variation of each dependent variable (moisture and fat). The PROC REG program was run for the Maximum R^2 (MAXR) criterion to determine the best model for prediction of each constituent.

RESULTS AND DISCUSSION

Chemical analysis results

Moisture and fat contents: Moisture loss from the food and oil uptake into the food are the major mass transfer processes during frying. Migration of water from the food leaves open pores through which the oil is absorbed by capillarity as a replacement process. As the frying time increases, the amount of moisture loss and fat uptake increases in the fried food. In this study, different levels of moisture and fat contents were produced by frying the samples for different times (1, 2, 3 and 6 min). This provided considerable ranges of change for the two constituents, as described later, for development of calibration models for prediction of the two constituents in a varying range.

The average total moisture content of chicken nugget samples varied from 2.14 to 0.93 g g^{-1} (db) when fried for up to 6 mins. The average crust moisture content varied from 0.87 to 0.19 g g^{-1} (db) within the same frying time. The average total moisture and average crust moisture content values are listed in Table 1.

The average total moisture content of fried samples was found to be highly correlated with average crust moisture content with R^2 of 0.97. The average total fat content of fried chicken nugget samples was changed from 0.14 to 0.32 g g^{-1}, (db) and the average crust fat contents ranged from 0.11 to 0.38 g g^{-1}, (db) within the 6 mins of frying Table 2.

Table 1: Mean values of total and crust moisture contents (MC, g g^{-1}, db) of the chicken nugget samples

Frying time (min)	Total MC (g g^{-1}, db)	S.D (g g^{-1}, db)	Crust MC (g g^{-1}, db)	S.D (g g^{-1}, db)
0	2.14	0.059	0.87	0.005
1	1.60	0.047	0.56	0.010
2	1.49	0.007	0.48	0.020
3	1.28	0.040	0.42	0.020
6	0.93	0.040	0.19	0.020

Table 2: Mean values of total and crust fat contents (g g^{-1}, db) of the chicken nugget samples

Frying time (min)	Total Fat content (g g^{-1}, db)	S.D (g g^{-1}, db)	Crust Fat content (g g^{-1}, db)	S.D (g g^{-1}, db)
0	0.14	0.0072	0.11	0.0200
1	0.25	0.0137	0.30	0.0044
2	0.30	0.0117	0.35	0.0064
3	0.34	0.0212	0.38	0.0137
6	0.32	0.0213	0.34	0.0165

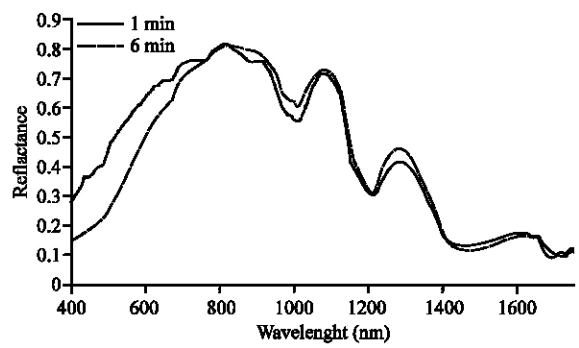

Fig. 3: Average reflectance spectra of a chicken nugget samples fried for 1 and 6 mins.

The total fat contents of the fried samples correlated with the crust fat contents (R^2 = 0.91). The ranges of moisture and fat content values obtained were close to the typical range reported for chicken nuggets[9,12,13]. The difference between the fat content results of this study and those reported by others might be due to different types of breading, initial moisture and fat contents and type of the oil used. The total moisture content was highly correlated with the total fat content (R^2 = 0.99) within about 3 mins frying. Strong relationship between moisture loss and fat uptake has been reported by several authors on other products[14-17]. However, in this study, this correlation broke down after 3 mins of frying. This was particularly important since it was necessary that the two constituents, namely moisture and fat, be treated as independent variables in the NIR calibrations.

VIS/NIR calibration results: Figure 3 shows reflectance spectra (400-1750 nm) of a chicken nugget sample, fried for 1 and 6 mins. The variations could be observed in visible range (400-700 nm), indicating color changes and in NIR region (700-1750 nm), indicating changes related to chemical compositions.

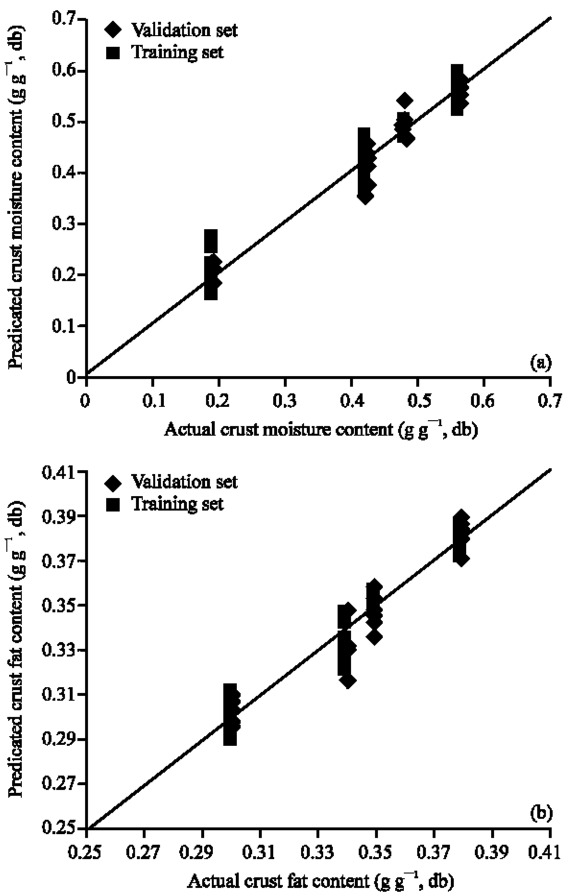

Fig. 4: Predicted crust moisture content (a) and fat content (b) vs. actual crust moisture content (a) and fat content (b) for the training and validation sets using Model 1, respectively

Calibration models for crust moisture and fat prediction:
Model 1: Calibration model based on spectral reflectance in the range of 400-1750 nm

A PLS calibration model was developed using spectra in the whole wavelength region of 400-1750 nm to predict moisture and fat contents of the crust. The optimal number of factors was determined to be 8 and 10 for moisture and fat contents, respectively. Crust moisture content was predicted with $R^2 = 0.95$ from cross-validation test and the RMSE value of 0.026 for the prediction of the validation set. Figure 4a shows the plot of predicted vs. actual crust moisture content obtained from cross validation of the training set and the validation test.

Crust fat content was predicted with $R^2=0.94$ from cross-validation test and the RMSE value of 0.006 for the prediction of the validation set. Figure 4b shows the plot of predicted vs. actual fat content obtained from cross validation of the training set and the validation test.

Model 2: Calibration model based on the spectral reflections in the selected wavelength regions

Common wavelength ranges of the most variation for both constituents (moisture and fat) were determined according to the PLS Beta coefficient plot of the GRAMS/AI software. Common regions of most variations were found to be within the ranges of 420-450, 550-670, 730-780, 810-1100, 1230-1450 and 1550-1600 nm.

Following the Beta coefficient procedure, results of multiple regression procedure of MAXR criterion indicated that the wavebands of the most variation for moisture determination were 555, 577, 817, 904, 967, 990, 1090, 1398 and 1576 nm, whereas for fat determination were 432, 438, 613, 621, 778, 891, 1044, 1230 and 1390 nm. Variations found in the visible range (400-700 nm) may be due to the color changes of samples fried for different times. Some of the bands found in the NIR region, in this study, were close to what were found in the literature. Bands of pure water are mainly observed at 1940, 1450, 1190, 970 and 760 nm due to O-H stretching overtones and combinations. These bands are subjected to shift in the spectrum of foods due to variations in hydrogen bonding. Bands of fat are mainly observed at 2310, 1765, 1734 and 1200nm in the NIR spectrum. These bands arise from overtones and combinations of CH_2 in fatty acid structure[18]. Mitsumoto *et al.*[19] observed bands of water at 1388, 1760, 2150 and 2322 nm and bands of fat at 1350, 1534, 1978 and 2294 nm in beef cuts. Misra *et al.*[20] used bands of 918, 928, 940, 950, 968, 975, 985, 998, 1010, 1023, 1037 and 1045 for determination of oil content of groundnuts. Alomar *et al.*[10] observed bands of water at 964, 1440 and 1960 and bands of fat at 928, 1760 and 2310 nm in Bovine meat. Leroy *et al.*[21] observed bands of water at 980, 1450, 1950 nm and bands of fat at 1200 and 1800 nm.

The results of the MAXR multivariate regression analysis verified the selection of the wavelength regions in Beta coefficient plots since the selected regions covered the peaks found by the MAXR analysis. Validation data set was used to evaluate the prediction accuracy of the MAXR multivariate regression models for both moisture and fat prediction. Moisture and fat contents were predicted with R^2 values of 0.98 and 0.97, respectively.

Model 2 for prediction of crust moisture and fat contents was developed using the selected wavelength regions. Crust moisture and fat contents were predicted with the R^2 values of 0.94 and 0.92 from cross-validation test and the RMSE values of 0.038 and 0.009 for the prediction of the validation set, respectively. Figure 5a and 5b show the plots of predicted vs. actual crust moisture and fat contents obtained from cross validation of the training set and the validation test, respectively.

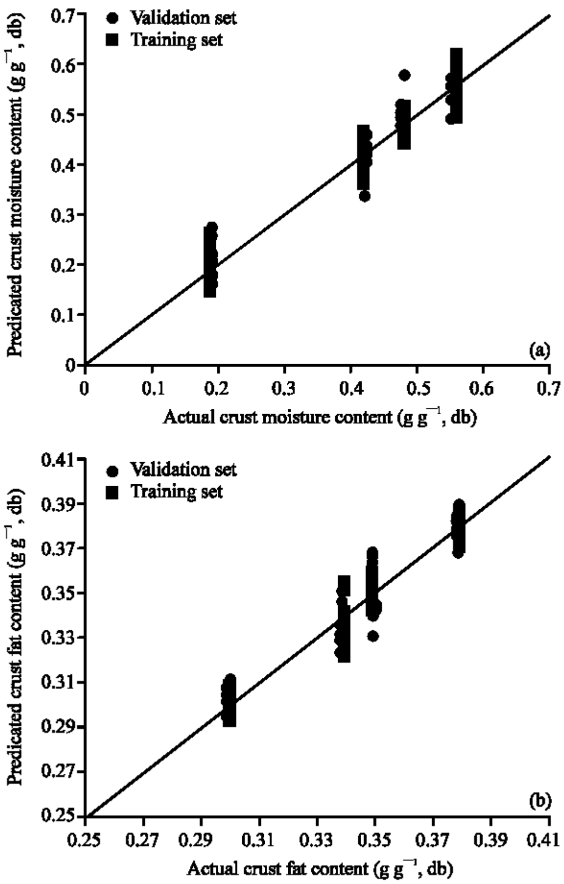

Fig. 5: Predicted crust moisture content (a) and fat content (b) vs. actual crust moisture content (a) and fat content (b) for the training and validation sets using Model 2, respectively.

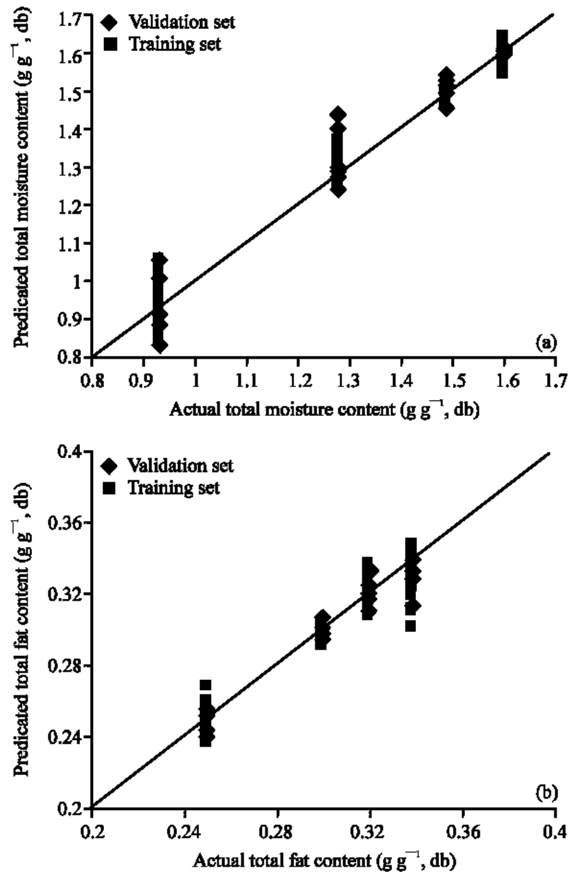

Fig. 6: Predicted crust moisture content (a) and fat content (b) vs. actual crust moisture content (a) and fat content (b) for the training and validation sets using Model 3, respectively.

Model 3: Calibration model based on the spectral reflection in the range of 400-1750 nm

With the same procedures used for crust moisture and fat prediction calibration models, total moisture and fat contents were predicted both with the R^2 value of 0.94 from cross-validation test and the RMSE values of 0.07 and 0.012 for the prediction of the validation set using the PLS calibration model with the optimum number of factors of 9 for both constituents. Figure 6a and 6b show the plots of predicted vs. actual total moisture and fat contents obtained from cross validation of the training set and the validation test.

Model 4: Calibration model based on the spectral reflection in the selected wavelength regions

With a similar procedure for selection of feature wavelengths as used for crust analysis calibration, the same wavelength r anges were found to show the highest contribution in calibration Model 3. The multivariate regression models obtained from the MAXR criterion of SAS analysis were able to predict the moisture and fat contents with R^2 values of 0.96 and 0.94. Using the similar PLS calibration procedures, total moisture and fat contents were predicted with R^2 of 0.92 from cross-validation test and the RMSE values of 0.105 and 0.017 for the prediction of the validation set. Figure 7a and 7b show the plots of predicted vs. actual total moisture and fat contents obtained from cross validation of the training set and the validation test, respectively.

Although the spectral information were based on the readings from the surface (crust) of the chicken nugget samples, high correlations were obtained for prediction of total moisture and total fat contents. This could be due to correlation between the total moisture content and crust moisture content (R^2 = 0.97) and correlation between total fat content and crust fat content

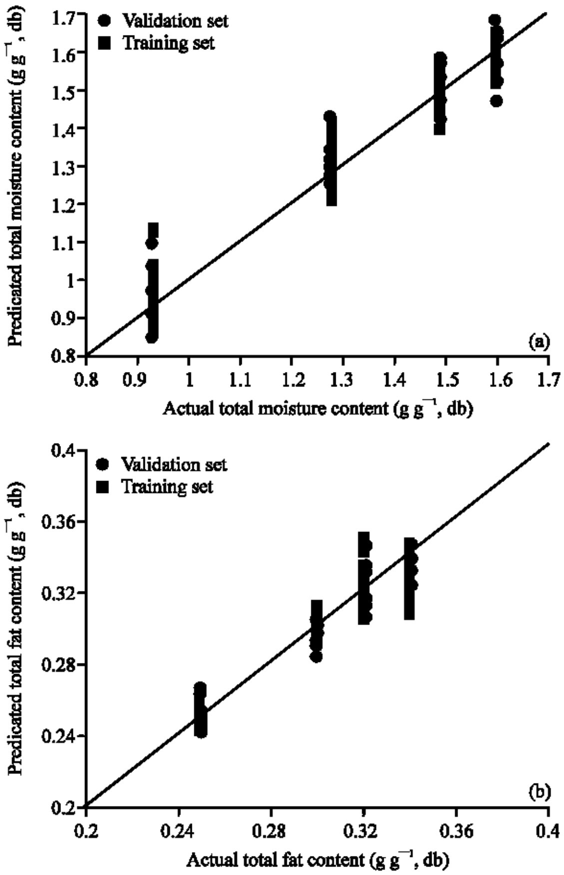

Fig. 7: Predicted crust moisture content (a) and fat content (b) vs. actual crust moisture content (a) and fat content (b) for the training and validation sets using Model 4, respectively.

(R^2 = 0.91) obtained in this study. However, as expected, the validation RMSE values obtained for the total moisture and fat prediction were lower than those obtained for crust moisture and fat prediction.

CONCLUSION

Results of this study indicated that the developed calibration models could track the moisture and fat content changes of fried chicken nuggets with the accuracy of R^2 values of 0.92.

Because of the high correlation between the total moisture and crust moisture content and the correlation between total fat and crust fat content, VIS/NIR calibration models could be used to predict the total moisture and fat contents based on the reflectance readings from the crust.

Feature wavelength ranges, 420-450, 550-670, 730-780, 810-1100, 1230-1450 and 1550-1600nm, selected in this study can be used to design rapid systems of quality evaluation of fried chicken nuggets.

VIS/NIR spectral analysis was proved to be a straightforward and fast method without requiring sample preparation and application of hazardous solvents. The new hyperspectroscopic techniques provide a capability to analyze spectral characteristics within a continuous wider wavelength range comparing to a common spectral techniques. This allows a detailed study of spectral responses regarding to the constituent(s) of interest. Once the calibration model is developed, the VIS/NIR instrument is capable of doing the moisture and fat analysis in few minutes.

REFERENCES

1. Anderson, N.M. and P.N. Walker, 2003. Measuring Fat Content of Ground Beef Stream Using On-Line Visible/NIR Spectroscopy. Transactions of the American Society of Agric. Eng., 46: 117-124.
2. Baik, O.D. and G.S. Mittal, 2005. Heat and Moisture Transfer ad Shrinkage Simulation of Deep-fat Tofu Frying. Food Res. Intl., 38: 183-191.
3. Ngadi, M.O., K.C. Watts and L.R. Correia, 1997. Finite Element Method Modeling of Moisture Transfer in Chicken Drum During Deep-fat Frying. J. Food Eng., 32: 11-20.
4. Budzaki, S. and B. Sergua, 2005. Moisture Loss and Fat Uptake During Deep Fat Frying of "Krostula" Dough. European Food Res. Technol., A.220: 90-96.
5. Moreira, R.G., M.E. Castell-Perez and M.A. Barrufet, 1999. Deep Fat Frying: Fundamentals and Applications. Maryland, USA. Aspen Publications.
6. Baumann, B. and F. Escher, 1995. Mass and Heat Transfer During Deep-Fat Frying of Potato Slices-I. Rate of Drying and Oil Uptake. Lebensm.-Wiss u.-Technol., 28: 395-403.
7. Association of Analytical Communities, 2000. Official Methods of Analysis of AOAC International. 17th Ed., Maryland, USA.
8. Buning-Pfaue, H., 2003. Analysis of Water in Food by Near Infrared Spectroscopy. Food Chem., 82: 107-115.
9. Togerson G., J.F. Arnesen, B.N. Nilsen and K.I. Hildrum, 2003. On-line Prediction of Chemical Composition of Semi-frozen Ground Beef by Non-invasive NIR Spectroscopy. Meat Sci., 63: 515-523.
10. Misra, J.B., R.S. Mathur and D.M. Bhatt, 2000. Near-infrared Transmittance Spectroscopy: A Potential Tool for Non-destructive Determination of Oil Content in Groundnuts. J. Food Sci. Agric., 80: 237-240.

11. Alomar, D., C. Gallo, M. C. Castaneda and R. Fuchslocher, 2003. Chemical and Discriminant Analysis of Bovine Meat by Near Infrared Reflectance Spectroscopy (NIRS). Meat Sciences, 63: 441-450.
12. El-Dirani, K., 2003. Textural and Mass Transfer Characteristics of Chicken Nuggets During Deep Fat Frying and Oven Baking. M.Sc. Thesis. McGill University. Montreal, QC., pp: 44-96.
13. Li, Y., 2005. Quality Changes in Chicken Nuggets Fried in Oils with Different Degrees of Hydrogenation. M.Sc. Thesis. McGill university. Montreal, QC., pp: 34-45.
14. Altunakar, B., S. Sahin and G. Sumnu, 2003. Functionality of Batters Containing Different Starch Types for Deep-fat Frying of Chicken Nuggets. European Food Res. Technol., 218: 318-322.
15. Gamble, M.H., P. Rice and J.B.D. Seldman, 1987. Relationship Between Oil Uptake and Moisture Loss During Frying of Potato Slices from c.v. Record U.K. tubers. Intl. J. Food Sci. Technol., 22: 233-241.
16. Rice, P. and M.H. Gamble, 1989. Modeling Moisture Loss during Potato Slice Frying. Intel. J. Food Sci. Technol., 24: 183-187.
17. Singh, R.P., 1995. Heat and Mass Transfer in Foods during Deep Fat Frying. Food Tech., 49: 134-137.
18. Kassama, L.S., 2003. Pore Development in Meat Products during Deep-Fat Frying. Ph.D. Thesis. McGill University. Montreal. QC., pp: 37-52.
19. Osborne, B.G., T. Fearn and P.H. Hindle, 1993. Applications of Near Infrared Spectroscopy in Food and Beverage Analysis. In: Practical NIR Spectroscopy with Applications in Food and Beverage Analysis. Ed. D. Browning. Singapore. Longman Singapore Publishers (Pte) Ltd. pp: 145-199.
20. Mitsumoto, M., S. Maeda, T. Mitsuhashi and S. Ozawa, 1991. Near-Infrared Spectroscopy Determination of Physical and Chemical Characteristics in Beef Cuts. J. Food Sci., 56: 1493-1496.
21. Leroy, B., S. Lambotte, O. Dotreppe, L. Istasse and A. Clinquart, 2003. Prediction of Technological and Organoleptic properties of beef Longissimus thoracis from Near-infrared Reflectance and Transmission Spectra. Meat Sci., 66: 45-54.