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Research Article

Prediction of chicken meatball quality through NIR spectroscopy and multivariate analysis

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Abstract

Near Infrared (NIR) Spectroscopy leads a great opportunity to replace the expensive and time-consuming chemical conventional analysis for determination of the quality of meat products. This study was conducted aiming to evaluate the feasibility of NIRS and to establish a rapid assessment method to easily predict the quality of chicken meatball. Samples of meatball (n=123) were collected from Golden Harvest Company of Bangladesh. After collecting sample, spectra were obtained prior to analysis and a total of 369 NIRs were collected and stored in computer by DLP NIR scan Nano Software. To generate reference data 123 meatball samples were analyzed for proximate components, instrumental color CIE L*, a*, b*, and pH of meatball. After that a partial least square regression model for calibration and cross validation were developed for data analysis using The Unscrambler X software. Accuracies of the calibration models were evaluated using the root mean square error of calibration ($RMSE_C$), root mean square error of cross-validation ($RMSE_{CV}$), coefficient of calibration (R^2_C) and coefficient of cross validation (R^2_{CV}). Calibration equations were developed from reference data using partial least squares regressions. The standard deviation is 2.41, 0.14, 2.1, 0.41, 1.31, 0.31, 1.26, 0.38, and 0.38 for L*, a*, b*, pH, DM, moisture, CP, EE and ash respectively which indicates that all values are adequate for analytical purposes. Predictive ability of the models was assessed by coefficient of determination of cross-validation (R^2_{CV}) and root mean square error of cross-validation. Predictions were good (R^2_{CV}=0.84) for lightness (L*), (R^2_{CV}=0.72) for redness (a*), (R^2_{CV}=0.77) for yellowness (b*), (R^2_{CV}=0.78) for pH, (R^2_{CV}=0.73) for CP, (R^2_{CV}=0.83) for EE (R^2_{CV}=0.72) for moisture, (R^2_{CV}=0.72) for DM and (R^2_{CV}=0.74) for ash. From the results, it can be concluded that NIRS can be used for the rapid assessment of physico-chemical traits of chicken meatball.

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Introduction

Meat products like sausages, meat patties, meat balls, etc. are very popular since they are delicious, nourishing, and can be preserved for a long time (Islam et al., 2018; Boby et al., 2021; Akhter et al., 2022; Khatun et al., 2022; Hashem et al., 2022). To obtain protein, vitamins and minerals meat and meat products are the best sources (Londero et al., 2015) with important macro and micronutrients (Hashem et al., 2021). Because of quick cooking method and easy storage facility, a significant increase of meat products has occurred in global consumption over the time (Hidayat et al., 2018). A major portion of this meat is consumed through meat products (Igene et al., 2012). It indicates that the meat and meat products occupy a large proportion in people's daily food items. Worldwide meat has become an essential ingredient and praised greatly by the consumers (Lanza, 1983). Meat quality (color, pH, drip loss, cooking loss, CP, EE, ash, etc.) is economically and technologically significant not only for the food-processing sector but also for consumers as a key factor when choosing meat (Baset et al., 2003; Akhter et al., 2009; Prieto et al., 2009; Rahman et al., 2014; Bithi et al., 2020; Disha et al., 2020; Habiba et al., 2021). The quality of meat products are easily affected by many factors, such as transporting, storing time and condition, temperature condition etc. These factors can influence many characteristics such as color, tenderness, flavor, and juiciness (Prieto et al., 2008). Consumers consistently require these products to be of the highest quality, which is seen as essential to success in the very competitive market of today (Saba et al., 2018; Islam et al., 2019; Kamal et al., 2019; Rokib et al., 2019). Different techniques such as sensory analysis, chemical procedures and instrumental methods have been practiced to provide information about quality of meat products. Sensory analysis, Chemical procedures such as protein, fat analysis and instrumental methods like measuring pH and color are destructive, tedious, time consuming, environmentally unfriendly and require lengthy sample preparation (Modak et al., 2009; Rana et al., 2014; Haque et al., 2017; Rahman et al., 2020). Therefore, these traditional methods are less capable and not suitable for quick analysis and early detection of quality attributes in industrial and commercial processing. Meat processing industries needs accurate, faster, real-time, low-cost and non-chemical technologies for quality detection. To reduce economic losses during processing, meat industry has to supply high-quality products consistently and quality control procedures must be carried out (Liao et al., 2010; Akhter et al., 2020; Lina et al., 2020; Sarker et al., 2021). Hence, quality assurance and control are the main tasks in production and processing of meat and meat products. On the other hand, meat and meat product processing are also sometimes hazardous to human health which include chemicals (causing acute or long-term toxicity), biological agents (pathogenic bacteria, viruses), as well as physical objects (Xiong et al., 2014). For these above reasons and to maintain consumers' satisfaction, it is very important to provide quality product that covers customers' needs and market requirements. Therefore, it is a crucial element within the meat processing industry to accurately assess meat and guarantee the quality and safety. Near infrared spectroscopy (NIRS) is an analytical technique that uses a source producing light of known wave length pattern (usually

800–2500 nm) and that processes into a complete picture of the organic composition of the analyzed substance/material (Van Kempen, 2001). In published studies, most attention has been paid to the investigation of the ability of NIRS to predict chemical composition and quality traits. The research was also conducted on Chicken meatball (Vichasilp and Kawano, 2015) assessing NIR performance for the determination of chemical composition and some quality characteristics of it. Only few studies exist dealing with the ability of NIRS for the categorization of meat and meat products such as discriminating strains (Fumière et al., 2000), discriminating feeding regimes (Cozzolino and Murray, 2002), detecting frozen-thawed meat and finding RN-gene carriers (Josell et al., 2000).The existing researches indicated that NIR has been successfully applied to the quantitative determination of such attributes in Chicken meatball with high accuracy and the coefficients of determination (R) of some indicators were up to 0.90 between predicted and reference values. This method of quality prediction is contemporaneous demand in Bangladesh. So, in this circumstance NIRS is an ideal tool to study characteristics of meat and shows a great potential to replace the expensive and time-consuming chemical analysis of meat composition. In view of quality evaluation, the use of NIRS appears more promising when categorizing meat products into quality classes on the basis of meat quality traits for example discriminating between feeding regimes, discriminating fresh from frozen-thawed meat products, discriminating strains, etc. The aim of this study is to test the ability of NIRS as an early predictor of chemical composition and quality traits of Chicken meatball.

Materials and Methods

Experimental site

This experiment was conducted at Animal Science Laboratory under the Department of Animal Science, Bangladesh Agricultural University, Mymensingh.

Required equipment and preparation of instruments

The equipment required were plastic pot, refrigerator, crucible, microwave oven, burette, conical flask, pipette, jar, water bath, petri dishes, HANNA meat pH meter, digital food grade thermometer, Minolta colorimeter, knife, chopping board, water and tissue paper. All necessary instruments were cleaned with hot water and detergent powder and then autoclaved and dried properly before starting the experimental activities.

Sample collection

Chicken meatball samples were collected from Golden Harvest Company, a renowned Bangladeshi Company. All samples were collected from local commercial market known as K.R. Market, BAU, Mymensingh. The refrigerated Meatball samples were immediately transferred to the Animal Science Laboratory, Bangladesh Agricultural University, Mymensingh.

Sample preparation

Collected meatball samples were weight and then kept in tray for about 10-12 minutes to release moisture caused by refrigeration and then again weight for final value. A total of 123 meatball samples dissected from 10 packets of Golden Harvest meatball of 500g packet. For each meatball one sample was used for NIR experiments and the other one was used to evaluate the chemical characteristics.

NIR spectra acquisition

For infrared measurements meatball samples were scanned at 900-1700 wavelength for spectra through NIR spectroscopy and screening noisy spectra. NIR spectra were loaded by The Unscrambler X software (Import spectra). Data were imported, created category variables, variable sets and sample sets. The raw data were inspected and plotted. PCA on spectra and reference variables were determined. Calibration and validation model were developed. Decisions were taken upon pre-treatment and optimize model. Final model was validated and interpreted. Developed model will be executed to predict new samples and modification, if necessary.

Chemical and physical attributes analyses

Proximate components such as dry matter (DM), Ether Extract (EE), crude protein (CP) and ash were carried out according to the methods (AOAC, 1995). All analyses were done in triplicate and the mean value was reported. The differences in weight between the fresh and dried samples represent the water content. An oven (GALLENKAMP Hot Box Oven with Fan - Size 2 CHF097 XX2.5) was used for determining dry matter kept for 24 hrs at 105^{o} C. Crude protein (CP) was determined using total nitrogen content of each sample by using kjeldahl apparatus. Ether extract content was determined by Soxhlet apparatus using diethyl ether. Total ash content was measured using muffle furnace where porcelain crucibles with samples were heated at 550°C for 6 hours, then cooled inside desiccators and weighed.

Color value and pH measurement

Color value estimation

Color value was measured by using Minolta colorimeter. Color was evaluated on the freshly cut surface and measured by visible and near-infrared spectroscopy. The meatball color was expressed in terms of CIE values for lightness (L*), redness (a*), and yellowness (b*) using a Minolta color meter model CR-410.

pH value estimation

The pH value in meatball was measured by direct contact between the sensitive diaphragm of the electrode and meatball. Through the diaphragm differences in electrical load between the meatball and electrolyte solution (e.g., Potassium chloride, KCl) inside the glass electrode are measured and directly indicated as the pH-reading. In fresh meatball, it is needed to spray small amounts of distilled water onto it at the point of measurement (prior to inserting the electrode), because the operation requires some fluidity in the sample and the glass electrode should be thoroughly wet. The pH meter was calibrated before

use and adjusted to the temperature of the tissue to be measured. The electrode was rinsed with distilled water after each measurement.

Statistical analysis

All reference parameters and NIR spectra were statistically analyzed to develop calibration and validation model for prediction through The Unscrambler X software. Descriptive statistics, principal component analysis, partial least square regression, RMSE, slope and coefficient of determination were measured for prediction and validation of multivariate data generated from lab analyses and NIRS.

Statistical analysis and partial least squares (PLS) calibration model

Spectral data were analyzed with Unscrambler X software version 9.7 (Camo, Trondheim, Norway). Partial least squares (PLS) regression was used for statistical evaluation of spectral measurements and the data are expressed as mean, standard deviation and coefficient of variation. The data quality of the statistical set was analyzed for the analysis of the validation set for each model, based on the proportion coefficient of determination (R^2), the mean square error of calibration ($RMSE_C$), mean square error of cross-validation ($RMSE_{CV}$) (Geesink et al., 2003). The equations of evaluation of the prediction model were also determinants for assessing the quality of the model in cross-validation (Balage et al., 2015). The PLS regression models were constructed so as to maximize the data variation capacity with all preformulating data using the leave-one-out cross-validation (LDD_{CV}), which is a model validation technique to evaluate the validity External. The corresponding quadratic cross-validation error ($RMSE_{CV}$), cross-validation prediction errors and PLS regression are respectively obtained (Chen et al., 2005). The residuals of each model were used to construct the prediction model and calculate the ($RMSE_{CV}$) to determine the best predictive efficiency model for each characteristic, being the lowest value for each formula (Hubert and Branden, 2003). On the cross-validation process, the model was evaluated for its prediction capability using the determination coefficient of calibration (R^2c), standard error of calibration (SE_C) or root mean square error of calibration (RMSEc), determination coefficient of cross-validation (R^2cv), and standard error of cross-validation (SE_{CV}) or root mean square error of cross-validation (RMSEcv) (Qu et al., 2005). The predictive capacities of the equations were evaluated using residual prediction deviation value (RPD) (Williams, 1987). The residual predictive deviation (RPD), calculated as the ratio of the standard deviation of the reference parameters chemistry (SD) and the standard error of cross-validation (SD/SE_{CV}) it considered excellent when ≥ 3. On addition, the RPD should ideally be at least three, taking into account that the variation in the reference data is low, the values for R^2 and RPD cannot be high (Williams and Sobering,1996; Pérez-Marín et al., 2004). The range error ratio (RER) is the range of reference techniques values without a predictive set for $RMSE_P$ (Pérez-Marín et al., 2004). The (RER) value is obtained by calculating the division of the concentration amplitude of an analyze by the mean square error of calibration ($RMSE_{CV}$), where a model with ratio of error range (RER) values < 3 has small predictive capability, models with RER between 3 and 10 have low to moderate practical utility, and RER values > 10 indicate good practical utility (Williams, 1987). According to (Millmier et al., 2000), RER values > 12 indicate high predictability. An R^2 value of 0.80 is a referential measure for concrete multiple regression models (Shiranita et al., 2000). Reliability analysis indicates that a RPD > 3 and RER > 10 are required to improve the quality analysis indicate a good classification (Dagnew et al., 2004).

Results and Discussion

Reference values of color and physical traits of chicken meatball

Compositional values of chicken meatball samples given in Table 1, expressed on a fresh basis, that is, in the same form as samples were scanned. To provide an overview of the structure of the samples used in the investigation, the mean, range, standard deviation (SD), coefficient of variance (CV) for color parameters (L*, a*, b*), pH, dry matter (DM%), moisture (%), crude protein (CP%), ether extract (EE%) and ash (%) for chicken meatball determined by laboratory reference methods are summarized in Table 1.

Table 1. Descriptive statistics of chemical composition in the tested chicken meatball samples

Parameters	Mean ± SD (%)	CV (%)	Range (Min-Max)
L*	70.37 ±2.41	83.22	58.28-74.59
a*	0.94 ±0.14	6.49	0.6-1.21
b*	17.91 ±2.1	8.53	14-21.95
pH	6.35 ±0.14	0.023	6.35-6.7
DM (%)	23.18 ±1.31	17.67	20.45-26.43
Moisture (%)	76.82 ±1.31	58.57	73.57-79.55
CP (%)	16.19 ±1.26	12.88	13.89-19.4
EE (%)	4.7 ±0.38	3.06	3.55-4.98
Ash (%)	2.28 ±0.38	16.71	1.68-3.08

(L*=lightness, a*=redness, b*=yellowness)

Meatball color (L*, a*, b*) was quite normal. In case of L* mean value was 70.37, CV was 83.22 and highest value was 74.59 and lowest value was 58.28. Maximum, minimum and mean value was 1.21, 0.6 and 0.94 respectively in case of a*. The b* values averaged 17.91 and ranged from 14-21.95 which considered normal for chicken meatball sample (Sukthanaruk et al., 2018). Maximum value of pH was 6.7 and minimum was 3.34. The average pH value was 6.3. The range is considered normal for chicken meatball (Igene et al., 2012). The average value of moisture and protein was 76.82 and 16.19 where (Prieto et al., 2009) showed that protein and ash contents for the chicken meatball had values within the range of 10.93 to 16.06% and 1.92 to 2.82% respectively which are quite normal also.

NIRS calibration and prediction statistics

NIRS calibration and prediction statistics for color parameters (L*, a*, b*), pH, dry matter (DM %), moisture (%), crude protein (CP %), ether extract (EE %) and ash (%) of chicken meatball are presented in Table 2.

Table 2. NIRS calibration and prediction statistics for different parameters of chicken meatball

Parameters	R^2C	R^2CV	SD	RMSEC	RMSECV	RPD	RER
L*	0.891262	0.838267	2.41	1.151103	1.403858	1.72	11.61
a*	0.820634	0.724847	0.14	0.06099	0.07554	1.85	8.08
b*	0.83732	0.769647	2.1	0.843393	1.003598	2.09	7.92
pH	0.856664	0.783577	0.41	0.024804	0.030478	13.45	11.48
DM (%)	0.830365	0.720925	1.31	0.538109	0.690197	1.9	8.66
Moisture (%)	0.830365	0.720926	0.31	0.538109	0.690196	1.9	8.66
CP (%)	0.826803	0.727948	1.26	0.521269	0.653307	1.92	8.43
EE (%)	0.890252	0.832698	0.38	0.147441	0.182042	2.08	7.86
Ash (%)	0.823181	0.737801	0.38	0.159606	0.194412	1.95	7.20

(R^2c = calibration coefficient; R^2cv = cross-validation coefficient; SD = standard deviation; $RMSE_c$ = standard error of calibration; $RMSE_{cv}$ = standard error of cross-validation; RPD = residual standard deviation; RER = range error ratio)

A wide and even distribution in composition, along with precise reference analysis techniques are recognized as important characteristics of the calibration set of samples, in order to obtain a successful equation (Murray, 1986).In case of color; calibration coefficient was 0.891, 0.82, 0.837 for L*, a*, b* respectively, where (Prieto et al., 2008) showed successful predictions of coefficient of correlation for meatball color values L*, a* and b* are more than 0.8. In case of pH; cross-validation coefficient was 0.78, where (Igene et al., 2012) showed that the value was 0.91. It is slightly lower than the existent results. The causes of it may be due to differences in sample size and a wide and even distribution in composition, along with precise reference analysis techniques are recognized as important characteristics of the calibration set of samples, in order to obtain a successful equation. In this study calibration coefficient and cross-validation coefficient for dry matter, crude protein and moisture were 0.83, 0.83, 0.83 and 0.72, 0.73, 0.72 respectively. On the contrary standard error of calibration and standard error of cross-validation for dry matter, crude protein and moisture were 0.54, 0.52, 0.54 and 0.69, 0.65, 0.69 respectively. As the obtained results were compared with the available literature, Table 2 shows both the values of correlation coefficients and the coefficients of determination. Many authors have investigated the definition of the chemical parameters of meat using NIR spectroscopy (Tao and Ngadi, 2017). Prieto et al. (2009) show NIRS prediction in a number of chemical parameters in various kinds of meat and meat products. This review provides ranges of the determination coefficient of calibration for total protein R^2 = 0.11 to 0.99, dry matter R^2 = 0.52 to 0.98 and moisture R^2 = 0.21 to 0.98. R^2c for moisture and DM were 0.83 and 0.83 which considered normal for moisture 0.71–0.86 (Sukthanaruk et al., 2018). Present study also similar to those findings for moisture, dry matter and crude protein. Calibration coefficient of EE was 0.89 and cross-validation coefficient was 0.83, respectively. (Prieto et al., 2008) found calibration co efficient of fat was 0.85. It is also similar to existent results. Predictive ability of the PLS model is assessed by co-efficient of determination of cross-validation (R^2_{cv}) and root mean square error of cross-validation ($RMSE_{cv}$). The best model for each trait is selected on the basis of the highest co-efficient of determination of cross-validation (R^2_{cv}) and the lowest root mean square error of cross-validation ($RMSE_{cv}$) (Morgan and Hunt, 1994). R^2_{cv} were 0.84, 0.72, 0.77, 0.78, 0.72, 0.72, 0.73, 0.83 and 0.74 for L*, a*, b*, pH, dry matter, moisture, crude protein, ether extract and ash respectively. $RMSE_{cv}$ values are 1.4, 0.08, 1.00, 0.03, 0.69, 0.69, 0.65, 0.18 and 0.19 for L*, a*, b*, pH, dry matter, moisture, crude protein, ether extract and ash respectively. So, results above values indicate that PLS model has prediction ability. To assess the practical utility of the prediction models the ratio performance deviation (RPD) and the range error ratio (RER) were calculated. RPD were 1.72, 1.85, 2.09, 13.45, 1.9, 1.9, 1.92, 2.08 and 1.95 for L*, a*, b*, pH, dry matter, moisture, crude protein, ether extract and ash respectively. It indicates that all of the values are adequate for analytical purposes as values above 1.5 are adequate for analytical purposes (Londero et al., 2015). Range error ratio were 11.61, 8.08, 7.92, 11.48, 8.66, 8.66, 8.43, 7.86 and 7.2 for L*, a*, b*, pH, dry matter, moisture, crude protein, ether extract and ash respectively. The range of the reference data, RER value between 7-20 classify the model as fair to good and indicate it could be used for screening purposes and RER values between 21 and 30 indicate a good classification suggesting the model could be suitable for application in quality control (Vichasilp and Kawano, 2015). So, for the above RER values the model is fair to good.

Development of calibration model based on NIR spectra

Although (Sukthanaruk et al., 2018) reported that the NIR region covers the wave length range from 780 to 2,500 nm; we used the range of 900 to 1,700 nm as done in other studies evaluating meatball quality (Prieto et al., 2008; Vichasilp and Kawano, 2015; Rohman et al., 2016). Spectral data at full wavelength range (900-1700 nm) with 228 variables were modeled using PLS. To visualize graphically the performance of the PLS calibration models, the measured value and its predicted values resulting from the optimal PLS models are plotted and displayed in Figure 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8 and 4.9.

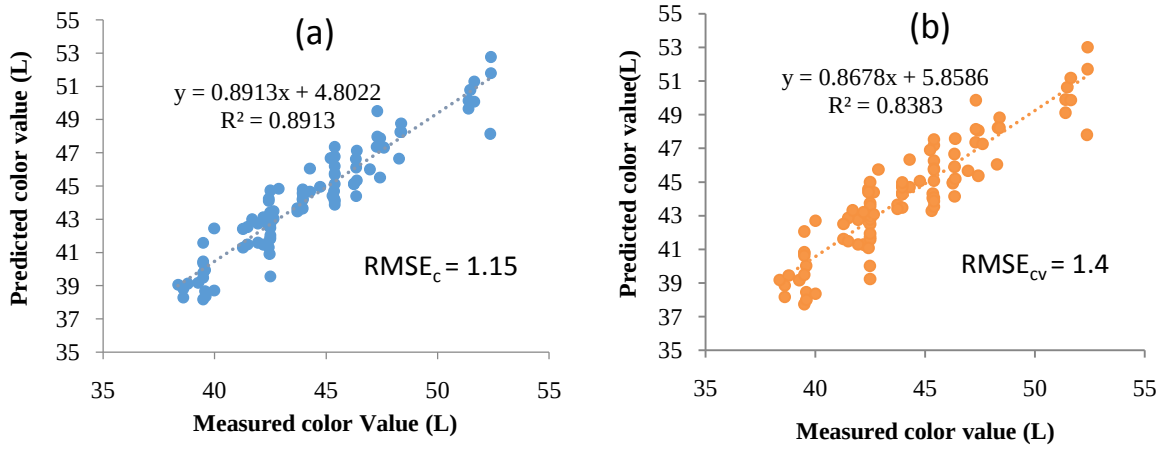

Figure1: Prediction of L* using PLS model for (a) calibration and (b) cross validation.

Conclusions

This study developed a multivariate partial least squares regression (PLSR) model to predict meat products chemical properties using NIRS spectra. The results demonstrated that NIRS can predict quality of meatballs with high accuracy. The finding from this study will be beneficial to both consumer and meatball industries in terms of quality control.

Conflicts of Interest

The authors declare that there are no potential conflicts of interests.

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