Prediction of Physical, Color, and Sensory Characteristics of Broiler Breasts by Visible/Near Infrared Reflectance Spectroscopy[1]

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ABSTRACT The feasibility of predicting pH, color, shear force, and sensory characteristics of chicken breasts deboned at 2, 4, 6, and 24 h postmortem by visible/near infrared reflectance spectroscopy (NIRS) in the 400 to 1850 nm region was determined. Prediction of physical attributes of Commission Internationale de l'Eclairage (CIE) color values (L*, a*, and b*), pH, and shear force had better accuracies than those of individual sensory attributes. Calibration and validation statistics for shear force and sensory traits indicated that visible/near infrared models were not significantly improved for cooked muscles compared with predictions based on raw muscle characteristics. On the basis of predicted shear values from the partial least squares (PLS) model, breast samples were classified into "tender" and "tough" classes with a correct classification of 74.0% if the boundary was set at 7.5 kg. The model developed from measured shears using soft independent modeling of class analogy/principal components analysis (SIMCA/PCA) showed nearly the same classification success.

(*Key words*: chicken meat, color, sensory, tenderness, visible/NIR spectroscopy)

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INTRODUCTION

Color, appearance, and texture are important factors that consumers will consider before making a decision to buy poultry. Instrumental (e.g., Warner-Bratzler (W-B) shear force measurement and Commission Internationale de l'Eclairage (CIE) L* a* b* color measurements) or sensory evaluation techniques can provide reliable information about poultry meat quality (Lyon and Lyon, 1991). However, these techniques are destructive, time consuming, and unsuitable for on-line application. The development of fast, nondestructive, accurate, and on-line/at-line techniques is critical to increase processing efficiency. Visible/near infrared spectroscopy (NIRS) could form the basis for such techniques due to speed, ease of use, and lesser interference from moisture or color of meat samples.

Visible/NIR spectroscopy has found considerable application in safety and quality control issues of poultry meat products. Applications include the quantitative evaluation of physical characteristics of heat-treated chicken patties (Chen and Marks, 1998), prediction of chemical components in chicken muscles (Cozzolino et al., 1996), discrimination of "slow-growing" chickens from "industrial" ones (Fumiere et al., 2000), identification of fresh and frozen chicken meat (Lyon et al., 2001), and classification of chicken carcasses into wholesome and unwholesome classes at the processing plant (Chen et al., 1996). However, no studies have been conducted that included the prediction of selected physical and color characteristics and of sensory properties of chicken meat from visible/NIR measurement.

The objective of this study was to examine the potential of visible/NIRS for the prediction of instrumental parameters, including pH, color, shear values, and of sensory flavor and texture attributes of poultry muscles. To closely simulate a commercial situation, broiler breasts were deboned at different postmortem times. In addition, we present a comparison of the prediction of instrumental texture and sensory characteristics between raw and cooked meats using partial least squares (PLS) regression.

MATERIALS AND METHODS

Broiler Breast Samples

Commercially grown, mixed-sex broilers (n = 144) were used for the study. Carcasses were obtained immediately

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Abbreviation Key: a* = redness; b* = yellowness; CIE = Commission Internationale de l'Eclairage; L* = lightness; NIRS = near infrared spectroscopy; PCA = principal component analysis; PLS = partial least squares; RMSEC = root mean square error of calibration; RMSEV = root mean square error of validation; SIMCA = soft independent modeling of class analogy; W-B = Warner-Bratzler.

after they exited a flow-through, paddle-type chiller (60 min) in a local commercial processing plant and transported to the laboratory (15 min). Carcasses averaged 1.5 kg dressed weight. The carcasses were randomly subdivided into 4 groups of 36 carcasses corresponding to 4 postmortem deboning times of 2, 4, 6, and 24 h. Breast muscles for the 2-h group were cut from carcasses within 20 min of arrival at the lab. Carcasses aged for 4, 6, or 24 h before muscle removal were kept on ice in containers placed in a 0°C cold room until the appropriate deboning time. Breast muscles were removed from the left and right sides of each carcass using the technique of Hamm (1981). Right sides were individually placed in polyethylene heat-and-seal bags, which were then labeled, sealed, and placed in a –30°C freezer prior to cooking and evaluation (W-B shear force, cook loss, and sensory evaluation). The raw left sides were evaluated immediately for instrumental color, visible/NIR spectra, and pH.

Measurements on Left Breasts

From the anterior section of the left raw breast, a 38-mm diameter core was cut for color and visible/NIRS analysis. To trim the core to the proper thickness, a cardboard backing (diameter, 38 mm; thickness, 5 mm) was inserted into the visible/NIR cylindrical sample cell (internal diameter, 38 mm; depth, 10 mm) that has an optical quartz surface. The cored breast meat was placed into the cell and sliced horizontally with a sharp knife to achieve a 5-mm thick sample. The top, trimmed section of the raw core was discarded. The core in the cell was removed and reinserted into another cell with the cut edge adjacent to the quartz window and then covered with a cardboard backing.

Color Measurements. Color measurements were made with a Minolta CR-210 colorimeter,[3] calibrated throughout the study through the visible/NIR cylindrical sample cell optical quartz window placed on the standard white ceramic reference (illuminant C). Color measurements of skinless broiler breast cores were made on the muscle section in the cylindrical cell through the quartz glass. Three consecutive random readings per sample were taken at different locations, and were averaged for each sample. Color was expressed in terms of CIE values for lightness (L*), redness (a*), and yellowness (b*).

Visible/NIRS Measurement. The raw cores in the spectrophotometer cell were scanned on a NIRSystems 6500 monochromator.[4] Reflectance measurements were recorded over the 400 to 2498 nm wavelength range at 2-nm intervals and 32 scans. The instrument was operated by the software package NIRS3 v.4.10.[5] The raw cores used for color and NIR measurements were placed in individual heat-and-seal bags and immediately cooked by immersion in an 85°C waterbath to an internal temperature of 80°C. After cooling the bags in tap water, the cooked samples were removed from the bags and measured for color and visible/NIR spectra as previously described. The obtained spectra were imported into Grams/32 using Grams/32 software.[6]

pH Measurement. pH measurements were made from 2-g portions cut from each raw left muscle immediately after deboning. Aliquots were placed into a 50-mL plastic test tube containing 25 mL of 5 m*M* iodoacetic acid (sodium salt)[7] and 150 m*M* KCl,[6] and homogenized using a PT 10/35 polytron mixer.[8] Before recording the pH values of the solutions on a Sentron model 2001 pH meter,[9] the electrode was rinsed with distilled water and dried with soft tissue paper.

Measurements of Right Breast Muscles

Cooking. For each replication (n = 4), individual frozen and bagged right breast samples were cooked by immersing the bags in 85°C water for about 25 min to achieve a maximum breast internal temperature of 80°C. After cooking, the bags were tempered for about 5 min at room temperature before opening and draining the liquid. To estimate cooking yield, the sample was weighed before freezing and reweighed after cooking. Cook yield was expressed as raw weight/cooked weight × 100.

Cooked breasts were sectioned for sensory and instrumental evaluations. Anterior and posterior ends of the muscles were discarded. Two adjacent 1.9-cm wide strips were removed from the breast by cutting around a template placed parallel to the muscle fibers and adjacent to the anterior end, as described by Lyon and Lyon (1996). One strip was used for instrumental evaluation. The second strip was cut into 2 subsections (1.9 × 1.9 cm) and used for sensory evaluation. Each panelist received 2 subsections from a single breast piece.

Sensory Evaluation. A 9-member trained descriptive sensory analysis panel evaluated the cooked samples using an established sensory lexicon (Lyon and Lyon, 1997). In 2-h panel sessions (8 h total), each panelist evaluated 2 cubed subsections from a breast sample from each treatment. Nine breasts per treatment were sampled at each of 4 replications. Samples were served at a temperature of 55°C and presented monadically to panelists in individual workstations equipped with controlled lighting and Compusense*five*[10] computerized sensory analysis systems. Panelists evaluated the flavor and texture of the samples, scoring each attribute using a numerical intensity scale ranging from 0 (none) to 15 (extreme). Samples were served at 20-min intervals. Water, apple, and unsalted crackers were used for mouth-cleansing after each sample. The order of samples served to panelists was randomized across sessions.

Shear Force Measurement. Intact strips for instrumental evaluations were covered and then sheared within 3 h of cooking. Room temperature samples were sheared

[3]Minolta Corp., Ramsey, NJ.
[4]NIRSystems, Silver Spring, MD.
[5]Infrasoft International, Inc., Port Matilda, PA.
[6]Galactic Industrious Corp., Salem, NH.
[7]Sigma Chemical Co., St. Louis, MO.
[8]Brinkmann Instruments, Westbury, NY.
[9]Sentron, Gig Harbor, WA.
[10]Compusense, Inc., Guelph, Ontario, Canada.

perpendicular to the longitudinal orientation of the muscle fibers with a Warner-Bratzler (W-B) shear blade (1-mm thick) attached to a Texture Analyzer (Model TA-XT2),[11] equipped with a 25-kg load cell (50-kg capacity). Test speed was 4.2 mm/s, travel distance was 55 mm, and calibration distance was 1 mm. Maximum force measured to cut the strips was expressed in kilograms. For each cooked breast, one strip was sheared in 2 locations and the average of the maximum forces was used for data analysis.

Chemometric Model for Data Analysis

Visible/NIR spectra (total = 144) representing the 4 groups of chicken muscles (2, 4, 6, and 24 h postmortem deboning time) were loaded into PLSplus/IQ package in Grams/32 to perform exploratory data analysis, namely PLS regression and principal component analysis (PCA). To develop prediction models, 96 of 144 spectra were used for the calibration set, and the remaining 48 (every third sample) spectra used for model validation. Chemometrical models were developed first in different spectral regions with various spectral pretreatments. The models revealed that, in general, the 400 to 1850 nm range provided the optimal results in calibration and validation sets. Classification models were developed using 2 classes, "tender" and "tough×, based on 2 sets of criteria for shear values and on soft independent modeling of class analogy (SIMCA) of PCA with a Mahalanobis distance (Galactic, 1996).

RESULTS AND DISCUSSION

Visible/NIR Spectra of Broiler Breast Muscles from Various Postmortem Deboning Times

Figure 1 shows the average visible/NIR reflectance spectra of raw broiler breast muscles deboned at 2, 4, 6, and 24 h postmortem. There were at least 5 broad bands with 2 (430 and 550 nm) in the visible region (400 to 750 nm) and 3 (980, 1195, and 1450 nm) in the NIR region (750 to 1850 nm). An earlier study on a variety of chicken muscles concluded that the bands at 430 and 550 nm arise mainly from deoxymyoglobin and oxymyoglobin pigments, respectively (Liu and Chen, 2000). Intense bands at 980, 1195, and 1450 nm are most likely due to the second overtone of the OH-stretching mode of water, the second overtones of the CH-stretching modes, and the first overtones of the OH/NH-stretching modes of selfassociated and water-bonded OH/NH groups in muscles (Osborne et al., 1993).

The visible/NIR spectral intensity variations in the 400 to 1850 nm region were not significant due to deboning time. This was probably due to the relatively short postmortem periods (no longer than 24 h) and because the muscles were freshly processed and cut (not frozen). Relatively large variation in visible/NIR spectra (not shown) was observed among the individual breast muscles in each of 4 groups. This variation is in agreement with Lyon and Lyon (1990, 1997) who observed large variation in shear values at earlier deboning times. The large variation could be indicative of the biochemical activity involved in the onset and resolution of rigor. Despite this variation, the spectra provide comprehensive information on chemical, physical, and structural properties in breast muscles.

To compare the models developed from raw and cooked muscles, visible/NIR spectra of cores from identical breasts after cooking were collected and their representative spectra are shown in Figure 2. Generally, 5 broad

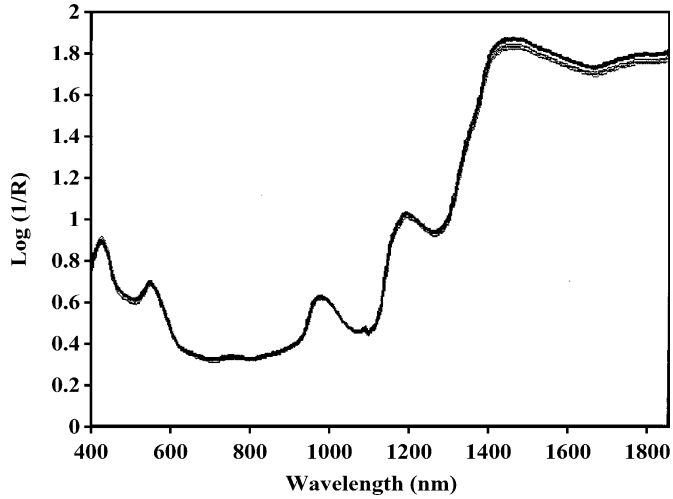

FIGURE 1. Average visible/near infrared reflectance spectra of raw chicken breasts deboned at 2, 4, 6, and 24 h postmortem in the 400 to 1850 nm region.

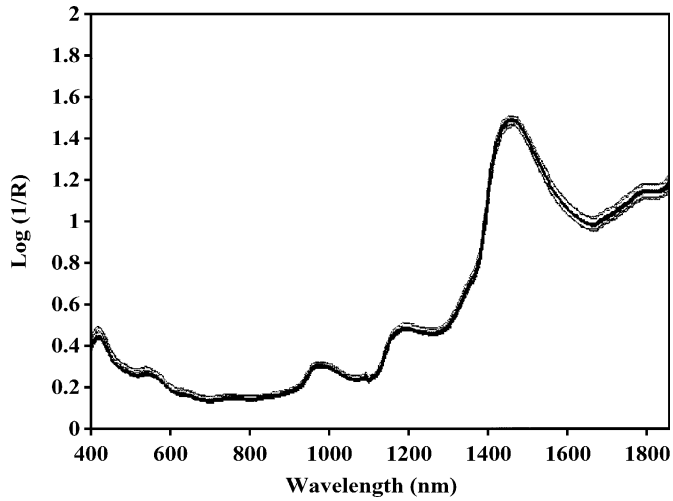

FIGURE 2. Average visible/near infrared reflectance spectra of cooked chicken breasts deboned at 2, 4, 6, and 24 h postmortem in the 400 to 1850 nm region.

[11]Texture Technologies Corp., Scarsdale, NY.

TABLE 1. Reference values of range, mean, and standard deviation for pH, CIE L*a*b*[1] color values, cook yield, Warner-Bratzler shear force, and sensory traits of broiler breast muscles removed from the carcasses at various times postmortem[2]

	Calibration set			Validation set		
Breast characteristics	Range	Mean	SD	Range	Mean	SD
Raw meat						
pH	5.56 to 6.35	6.09	0.19	5.65 to 6.40	6.01	0.17
L* value	41.16 to 55.04	47.11	2.81	42.29 to 52.65	46.67	2.13
a* value	1.60 to 6.70	3.80	0.95	2.41 to 7.28	4.11	1.10
b* value	0.32 to 7.04	3.76	1.36	0.53 to 6.72	3.67	1.40
Cooked meat						
Cook yield (%)[3]	64.06 to 80.69	73.10	3.53	68.32 to 80.87	74.91	2.72
Shear force (kg)	2.74 to 17.32	6.64	3.09	2.62 to 14.62	6.36	3.14
Sensory flavor[4]						
Brothy	1.35 to 6.44	3.75	0.86	2.70 to 5.25	3.80	0.55
Chickeny-meaty	3.00 to 5.69	4.24	0.58	3.15 to 4.65	4.10	0.36
Cardboardy	0.82 to 5.17	2.71	0.98	0.97 to 4.57	2.53	0.94
Wet feathers	0.82 to 4.65	2.51	0.93	2.09 to 5.02	3.23	0.68
Bloody-serumy	0.82 to 6.37	3.27	1.43	1.50 to 4.65	3.49	0.64
Sweet	0.07 to 3.90	2.25	0.86	0.15 to 3.15	2.21	0.64
Salty	0.07 to 3.82	2.08	0.87	0.30 to 3.22	1.97	0.62
Sour	0.37 to 4.50	2.83	0.94	2.09 to 4.57	2.90	0.58
Sensory texture[4]						
Springiness	1.79 to 6.44	3.90	1.13	0.89 to 7.19	3.39	1.34
Cohesiveness	2.40 to 9.00	5.39	1.65	2.32 to 9.37	5.17	1.56
Hardness	2.17 to 7.50	5.14	1.34	3.22 to 7.57	5.03	1.02
Moisture release	1.72 to 6.37	3.66	0.89	2.02 to 5.77	3.74	0.63
Particle size	1.50 to 6.07	3.54	0.98	1.57 to 5.09	3.28	0.92
Bolus size	1.20 to 5.69	3.83	1.01	1.72 to 5.40	3.59	0.91
Chewiness	2.54 to 9.30	4.96	1.38	3.07 to 9.22	4.96	1.05
Toothpack	1.20 to 5.92	3.60	1.07	1.95 to 5.47	3.86	0.78
Afterfeel-aftertaste[4]						
Metallic	0.67 to 6.00	3.08	1.36	1.95 to 4.80	3.42	0.76
Oily-greasy	0.00 to 3.22	1.43	0.96	0.00 to 2.62	0.90	0.76

[1]CIE L*a*b* = Commission Internationale de l'Eclairage color values: lightness (L*), redness (a*), and yellowness (b*).

[2]For calibration set, n = 96 for all variables except cook yield, for which n = 94. For validation set, n = 48.

[3]Cook yield calculated using the formula $w^* = (w_{cooked}/w_{raw}) \times 100$.

[4]Sensory scores based on intensity line scales where 0 = none and 15 = extreme.

bands (430, 550, 980, 1195, and 1450 nm) were still observed, but their relative intensities decreased and band position and shape changed. Spectral differences between Figures 1 and 2 indicated the extensive changes in appearance as well as physical and chemical properties of the chicken muscles when thermal treatments were applied (Kinsman et al., 1994; Chen and Marks, 1998).

Reference Values of pH, CIE L* a* b* Color, Cook Yield, Shear Value, and Sensory Attributes of Breast Muscles

Table 1 summarizes the mean, SD, and range of reference values in calibration and validation sets for pH, CIE color values (L*, a*, and b*), cook yield, W-B shear force, and 18 sensory attributes of breast muscles removed from the carcasses at 2, 4, 6, and 24 h postmortem, respectively. Principal component analysis of these reference values showed some differentiation of muscles deboned at different postmortem periods (Liu et al., 2004). The corresponding loading plot suggested a number of variables, including W-B shear force, cook yield, and most of the sensory attributes, that were effective in making the distinctions among deboning times. The results indicated

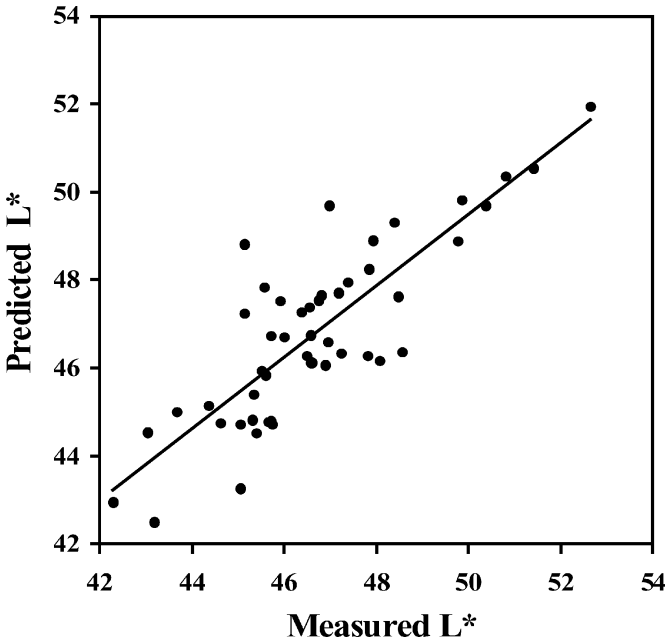

FIGURE 3. Correlation plot of measured vs. visible/near infrared-predicted CIE L* values (lightness).

TABLE 2. Statistics[1] in calibration and validation sets for pH, CIE L*a*b*[2] color values, cook yield, Warner-Bratzler shear force, and sensory traits from the visible/near infrared spectra of raw broiler breasts

Breast characteristics	Optimal factors[3]	Calibration set		Validation set			
		R^2	RMSEC	R^2	RMSEV	Bias	Ratio
Raw meat							
pH	6*	0.68	0.11	0.91	0.15	0.027	1.14
L* value	8*	0.84	1.19	0.94	1.21	0.114	1.76
a* value	11**	0.83	0.42	0.38	0.87	–0.321	1.27
b* value	6*	0.78	0.66	0.80	0.95	–0.155	1.47
Cooked meat							
Cook yield (%)	3*	0.66	2.42	0.49	2.67	–0.532	1.02
Shear force (kg)	5**	0.45	2.35	0.29	2.65	0.322	1.18
Sensory flavor[4]							
Brothy	4*	0.20	0.78	0.37	0.71	–0.106	0.78
Chickeny-meaty	4*	0.18	0.54	0.38	0.45	0.108	0.80
Cardboardy	5*	0.35	0.81	0.29	1.00	0.159	0.94
Wet feathers	5*	0.29	0.80	0.62	1.20	–0.782	0.56
Bloody-serumy	2*	0.13	1.36	0.49	0.90	–0.312	0.71
Sweet	2**	0.02	0.86	0.05	0.64	0.049	1.00
Salty	3**	0.12	0.83	0.21	0.73	0.056	0.85
Sour	3*	0.17	0.87	0.43	0.70	–0.193	0.82
Sensory texture[4]							
Springiness	4*	0.27	0.99	0.15	1.65	0.490	0.82
Cohesiveness	6*	0.30	1.42	0.38	2.04	–0.005	0.77
Hardness	5*	0.21	1.23	0.45	1.14	–0.006	0.72
Moisture release	4*	0.21	0.81	0.42	0.79	–0.041	0.79
Particle size	5*	0.24	0.88	0.37	1.11	0.224	0.83
Bolus size	5**	0.18	0.94	0.29	0.97	0.242	0.93
Chewiness	5*	0.28	1.21	0.63	1.30	–0.006	0.81
Toothpack	3*	0.13	1.01	0.24	0.87	–0.204	0.89
Afterfeel-aftertaste[4]							
Metallic	4*	0.24	1.21	0.79	1.20	–0.496	0.63
Oily-greasy	3**	0.04	0.96	0.09	0.95	0.538	0.80

[1]Calibration set, n = 96 for all except cook yield, for which n = 94; validation set, n = 48; RMSEC = root mean square error of calibration; RMSEV = root mean square error of validation; Bias = mean visible/NIR predicted value minus mean reference value; Ratio = Standard deviation of reference value / RMSEV (= SD / RMSEV).

[2]CIE L*a*b = Commission Internationale de l'Eclairage color values: lightness (L*), redness (a*), and yellowness (b*).

[3] * = optimal factors with mean centering (MC) + multiplicative scattering correction (MSC) + 2nd derivative pretreatment; ** = optimal factors with MC + MSC pretreatment.

[4]Sensory scores based on intensity line scales where 0 = none and 15 = extreme.

that the variables were sensitive to chemical, physical, and structural changes in the muscles due to the deboning times, and subsequently could be used to describe the muscles.

Prediction of pH, CIE L a* b* Color, Cooking Yield, Shear Value, and Sensory Attributes from Visible/NIR Spectra*

Partial least squares regression models for 24 variables were developed using different spectral regions and a variety of data pretreatments. It revealed that, generally, the 400 to 1850 nm range provided the optimal results in calibration and validation sets. The visible/NIR model calibration and validation statistics for 24 variables of the raw broiler breast samples are summarized in Table 2. The optimal number of factors in the model for each variable, as determined by cross-validation of the calibration set, ranged from 2 to 11. Generally, the R^2 values in calibration and validation sets for cook yield, shear value, and sensory properties were lower than those for pH and CIE L* a* b* color values.

The ratio of the SD of reference value against root mean square error of validation (RMSEV) is often used as a dimensionless gauge of the ability of an NIR model to predict a property. A value of 1.0 or less indicates that the NIR model might lack modeling power. A value of greater than 2.5 indicates that the NIR model might be suitable for screening programs, and a value of greater than 5.0 is potentially useful in quality control (Williams and Sobering, 1993). Based on the scale of the ratio, the better models were those for the variables of pH, CIE color values (L*, a*, and b*), cook yield, and shear force, with ratios ranging from 1.02 to 1.76. With ratio values less than 1, the individual sensory attributes could not be modeled by visible/NIRS. Sensory attributes had a narrow range of intensity scores, and as individual components that make up the overall complex of sensory perceptions, single attributes may be more difficult to model than individual chemical or physical parameters.

Among the nonsensory models, CIE L* (SD/RMSEV = 1.76) was more accurately modeled than CIE a* (1.27), CIE b* (1.47), pH (1.14), cook yield (1.02), or shear force (1.18). Examples of plots for the reference vs. visible/NIR

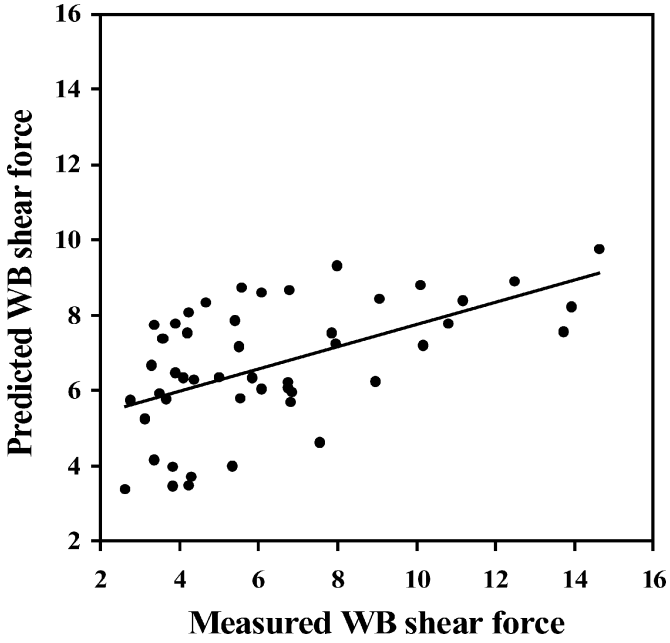

FIGURE 4. Correlation plot of measured vs. visible/near infrared-predicted Warner-Bratzler (WB) shear force.

predicted values in the validation set are shown in Figures 3 through 5 for CIE L*, shear force, and chewiness, respectively. These plots indicate how well the visible/NIR models work for the reference values from different measurements. If samples show a narrow range in individual reference data, or if the error in the evaluation is large compared with the standard deviation, the models indicate increasing difficulty in finding robust visible/NIR calibration. Cozzolino et al. (1996) found that visible/NIR spectroscopy could be used to determine the amount of moisture, protein, and fat in minced chicken breasts with an SD/RMSEV of 2.56, 7.69, and 1.06, respectively.

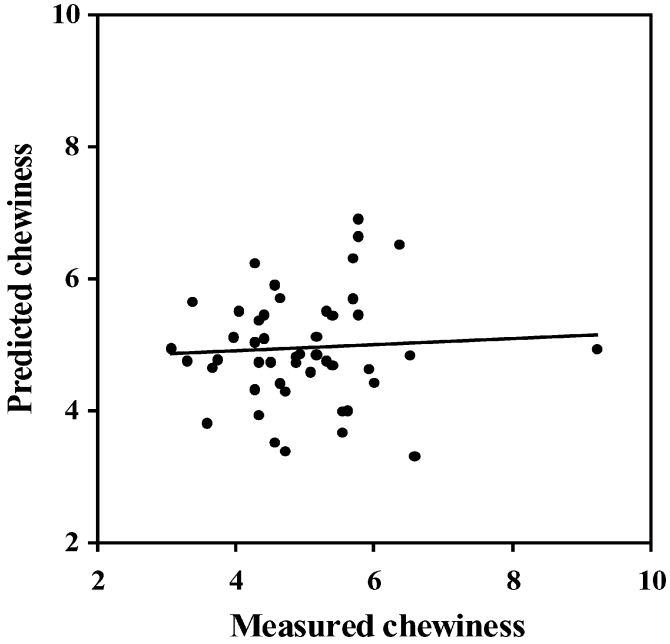

FIGURE 5. Correlation plot of measured vs. visible/near infrared-predicted chewiness.

Partial least squares models were also developed on W-B shear force values and sensory attributes, respectively, from the cooked breast muscles. The results are shown in Table 3. The SD/RMSEV ratios were highest for shear force (1.23). Several sensory attributes had ratios >0.93, including cardboardy, sweet, hardness, and bolus size. Generally, no models were improved significantly or influenced greatly from those developed for the raw breast muscles. Hence, visible/NIR spectroscopy of raw muscles could be further exploited to provide a reliable prediction of tenderness and sensory attributes.

Classification of "Tender" and "Tough" Broiler Meat from Visible/NIR Spectra of Raw Muscles

Broiler muscles were classified as "tender" and "tough" according to predicted W-B shear force values. The classification for the validation data set was performed using 2 types of criterion. One criterion chose the boundary between "tender" and "tough" as 7.5 kg, a value that was used by Lyon et al. (1985) as a distinction point between "tough" and "tender" for broiler breast meat. Simpson and Goodwin (1974) reported a shear value of 8.0 kg as "tough". The second criterion considered the ranges of 6.5 kg and below (tender) or 9.0 kg and above (tough). These values were reported by Lyon and Lyon (1991) as 2 of the 6 groups on a sensory scale ranging from "very tender" (<3.6 kg) to "very tough" (>12.6 kg) that related W-B shear values to consumer perceptions of broiler breast tenderness. The results are summarized in Table 4. Of the 34 meat samples in the validation set with a measured shear value less than 7.5 kg, 26 samples (76.5%) were predicted to have shear values less than 7.5 kg. Of the 14 meat samples in the validation set with measured shear values greater than 7.5 kg, 71.4% were predicted to have shear values greater than 7.5 kg. Therefore, the overall accuracy of the classification by the 7.5 kg criterion was 74.0%. If the ranges classifying the meat into "tender" and "tough" classes were narrowed (second criterion), the correct classification dropped from 74.0 to 37.2%. The lower classification rate was due primarily to meat samples with shear values >9 kg. Only 1 (11.3%) of 9 validation samples with shear value >9 kg was correctly classified using PLS.

Alternatively, the application of PCA was attempted (Galactic, 1996). The assignment of calibration and validation samples in the PCA model was the same as that in PLS model. Sixty-six spectra from meat samples with a measured shear forces less than 7.5 kg (representing "tender") and 30 spectra from meat samples with measured shear forces greater than 7.5 kg (representing "tough") were used for calibration development, and the additional 48 samples were used for the model validation. For each of the 2 classes, the optimal number of factors was suggested to be 5 and 5, respectively, for "tender" and "tough". By applying 2 SIMCA classes ("tender" and

TABLE 3. Statistics[1] in calibration and validation sets for Warner-Bratzler shear force, and sensory traits from the visible/near infrared spectra of cooked broiler breasts

		Calibration set		Validation set			
Breast characteristics	Factors[2]	R^2	RMSEC	R^2	RMSEV	Bias	Ratio
Shear force (kg)	7**	0.53	2.21	0.68	2.55	0.413	1.23
Sensory flavor[3]							
Brothy	6*	0.33	0.72	0.46	0.68	0.039	0.81
Chickeny-meaty	4*	0.30	0.50	0.70	0.48	0.154	0.74
Cardboardy	3*	0.20	0.89	0.12	0.96	0.182	0.98
Wet feathers	7*	0.46	0.71	0.52	1.10	–0.746	0.61
Bloody-serumy	5**	0.15	1.36	0.77	0.87	–0.178	0.74
Sweet	3*	0.10	0.83	0.22	0.68	0.042	0.94
Salty	2*	0.12	0.83	0.24	0.71	0.100	0.87
Sour	2*	0.11	0.90	0.35	0.73	–0.087	0.78
Sensory texture[3]							
Springiness	2*	0.14	1.06	0.08	1.52	0.497	0.88
Cohesiveness	2*	0.11	1.59	0.16	1.87	0.202	0.84
Hardness	5*	0.22	1.22	0.32	1.10	–0.018	0.93
Moisture release	3*	0.11	0.85	0.20	0.72	–0.102	0.87
Particle size	6*	0.32	0.84	0.39	1.07	0.299	0.86
Bolus size	3*	0.20	0.91	0.19	0.94	0.157	0.96
Chewiness	7**	0.37	1.15	0.83	1.29	–0.003	0.81
Toothpack	3*	0.11	1.02	0.18	0.90	–0.305	0.87
Afterfeel-aftertaste[3]							
Metallic	3*	0.14	1.28	0.60	1.20	–0.348	0.63
Oily-greasy	2**	0.07	0.94	0.14	0.97	0.559	0.79

[1]Calibration set, n = 96; validation set, n = 48; RMSEC = root mean square error of calibration; RMSEV = root mean square error of validation; Bias = mean visible/NIR predicted value minus mean reference value; Ratio = Standard deviation of reference value / RMSEV (= SD / RMSEV).

[2]* = factors based on calculation with mean centering (MC) + multiplicative scattering correction (MSC) + 2nd derivative pretreatment; ** = spectral pretreatment with MC + MSC.

[3]Sensory scores based on intensity line scales where 0 = none and 15 = extreme.

"tough") to validation samples (34 "tender" and 14 "tough") and employing the class assignment rule of lower Mahalanobis distance, the sample was identified as belonging in the group being modeled, i.e., either "tender" or "tough". The obtained result from SIMCA/PCA classification model is shown in Table 4 and is nearly the same as that from the PLS model.

The SIMCA/PCA classification model was also developed for the calibration set consisting of 56 spectra representing the "tender" meat samples (measured shear value less than 6.5 kg) and 18 spectra representing the "tough" meat samples (measured shear value greater than 9.0 kg) in the similar procedure. Applying the models to 39 validation samples (30 "tender" and 9 "tough") revealed an average of 63.9% correct classification (Table 4).

In summary, this study suggests that visible/NIR spectroscopy might have the feasibility to predict W-B shear value, color, pH, and sensory characteristics in broiler muscles. As expected, the predictive models of CIE L*, a*, b*, pH, and shear force have better accuracies than those of individual sensory attributes. Chemometric statistics indicated that the visible/NIR models were neither affected largely nor improved significantly by relating the reference values with the spectra of cooked meats rather than raw samples. From visible/NIR predicted tenderness values in the PLS model, breast samples were classified into "tender" and "tough" classes with a correct classification of 74.0% if the boundary was set at 7.5 kg. As an alternative, a model based on SIMCA/PCA of measured shear force values as an indication of tenderness

TABLE 4. Two-group classification of "tender" and "tough" broiler muscles in validation set from visible/near infrared spectroscopy based on predicted / measured Warner-Bratzler shear force values[1]

Criterion set[2]	Models[3]	Correct classification of "tender" meat (%)	Correct classification of "tough" meat (%)	Average (%)[4]
1 Tender = < 7.5 kg	PLS	76.5	71.4	74.0
Tough = > 7.5 kg	SIMCA/PCA	82.4	57.1	70.0
2 Tender = < 6.5 kg	PLS	63.3	11.1	37.2
Tough = > 9.0 kg	SIMCA/PCA	83.3	44.4	63.9

[1]Spectral pretreatment with mean centering (MC) and multiplicative scatter correction (MSC).

[2]Criterion set 1: samples in calibration set, n = 96; validation set, n = 48; criterion set 2: samples in calibration set, n = 74; validation set, n = 39.

[3]PLS = partial least squares; SIMCA = soft independent modeling of class analogy; PCA = principal component analysis.

[4]Mean of percentage of correct classification for "tender" and "tough" classes.

was attempted, and it showed nearly the same classification success.

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