PREDICTING INTRAMUSCULAR FAT, MOISTURE, SHEAR FORCE AND RATING PORK TENDERNESS USING VISIBLE/NEAR-INFRARED SPECTROSCOPY

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Abstract – Currently the meat industry requires fast, accurate and non-destructive methods for quality control of raw material and processes, either to meet their own market lack, or to meet the consumers' needs who are increasingly demanding. Published works in the last decade show that Vis/NIR spectroscopy has great potential to perform quantitative and qualitative analyses in meat and meat products and its models have good prediction accuracy. This work aims to answer the following questions: is the Vis/NIRS capable of predicting moisture, intra muscular fat and shear force in pork? Is the Vis/NIRS able to rate pork in tenderness classes? The results suggest that Vis/NIRS has moderate to low ability to predict moisture, intramuscular fat and shear force, but has great potential to classify correctly the pork loin into two tenderness classes.

Key Words – NIRS, Meat quality, Validation

I. INTRODUCTION

Accurately predicting the value of meat is critical to success in the meat industry. Producers and processors incur economic losses when meat quality is not accurately judged, such as when high quality, highly palatable pork is processed rather than sold fresh, or when lower quality pork is sold fresh and found unsatisfactory by consumers [1].
The measurement of major chemical constituents in fresh meat, such as fat, moisture or protein, is essential not only for labeling and consumer acceptance purposes, but also for ensuring the right balance in dry-cured or processed products [2].

Tenderness is often cited as the most important characteristics in meat quality attributes being directly linked to consumer's satisfaction and also to repurchase act [3].

Besides being time consuming, chemical composition analysis can also be expensive and use toxic reagents, and tenderness is commonly studied by means of slow and destructive methods such as texturemeters equipped with Warner–Bratzler, Kramer or compression devices [4].

Lately, reflectance spectrophotometers that span the near infrared (NIR) range to the visible (Vis) region of the spectrum have become easily available for research and industrial purposes and combining both the Vis and NIR regions in one instrument seems to make a considerable improvement in efficiency related to instrumental, sampling and analytical cost [1, 3, 5, 6]

Use of visible and near–infrared spectroscopy (Vis/NIRS) analysis is increasing in food and agricultural industries for monitoring, quality control, and analytical purposes, and, in this context, it may be able to provide an objective, consistent, rapid, accurate, and non–destructive method of evaluating meat to predict qualitative attributes and chemical composition in meat and meat products [1, 2, 3].

The aim of this work was to predict intramuscular fat, moisture, shear force and rate pork in tenderness classes using Vis/NIRS spectroscopy.

II. MATERIALS AND METHODS

Muscle samples
Animals were slaughtered at experimental abattoir of College of Animal Science and Food Engineering of University of São Paulo, in accordance to Humanitarian Slaughter Guidelines as required by Brazilian laws and carcass processing followed the common industry practices adopted in Brazil. To perform shear force

analysis, samples from *Longissimus* muscle at the 11^{th} rib were removed from 134 pig carcasses after 24 hours of chilling. To analyze moisture and intramuscular fat (IMF), samples were collected from ninth rib, under the same conditions mentioned above.

Intramuscular fat, moisture and shear force measurements

Tenderness was determined using the Warner-Bratzler shear force method (WBSF), according to AMSA recommendations [7]. Each sample was cooked in electric broiler cookery until a temperature of 40°C was reached. Then the sample was flipped and cooked until the final internal temperature of 71°C.

Moisture and IMF analyses were performed on the fresh samples after thawing. Moisture content was measured by oven drying the samples at 105ºC until constant weight [8]. IMF was determined using Soxhlet direct extraction with petroleum ether, without acid pre-treatment, for determination of free fat content [9]. Moisture and IMF composition were expressed as g/kg fresh weight.

Visible and near infrared measurements

Vis/NIR analysis was performed using a spectrophotometer model EPP2000-CXR-Srs (Stellarnet Inc., Tampa, FL) and the spectra were collected from 400 to 1,495 nm. Spectral resolution was set to five nm and five scans were averaged for every spectrum (204 data points). Reflectance (R) data were stored as log (1/R). Each sample was scanned twice at different locations throughout the sample.

Statistical analysis

Spectral data was analyzed by The Unscramble®X 10.1 software (CAMO Software AS, Oslo, Norway). Principal component analysis (PCA) was performed before partial least square regression (PLSR) models were developed. After PCA analysis, the raw spectra were transformed using different mathematical treatments [6] such as standard normal variate (SNV), multiple scatter correction (MSC), extended multiple scatter correction (EMSC), first and second derivative.

Before developing prediction equations the dataset was split into two datasets: a calibration set (83 samples) and a test-set (51 samples). The software randomly chose the samples for each datasets. The calibration set was used to develop prediction equations using the PLSR and Vis/NIR spectra to predict moisture, IMF and WBSF in pork. The calibration set was evaluated using cross validation. The resulting calibration equations were evaluated based on the coefficient of determination for calibration (R^2) and the standard error in cross validation. The prediction equations developed from the calibration set were also evaluated on the independent test-set samples, using test-set validation [10].

Vis/NIR's ability of rating pork into tenderness classes was tested using the predicted values (from calibration models) and reference WBSF values to test the percentage of samples correctly classified as tender (when WBSF < 45 N/cm) or tough (when WBSF ≥ 45 N/cm).

III. RESULTS AND DISCUSSION

The ratio between the standard error for calibration (SEC) and the standard error of cross validation within the calibrated data set (SECV) varied between 0.59 and 1.17 (Table 1), indicating a sufficiently robust calibration [11]. The ratio between the standard error of prediction (SEP) and the SEC ranged from 1.07 to 1.62 (1.28 on average). According to Savenije et al. (2006) [11], this ratio is very acceptable with regard to the accuracy of the calibration.

The Vis/NIRS based model for moisture and IMF generated in this study exhibited performance well below previously reported in the literature (Table 1).

Table 1: Coefficients of determination (R^2), standard error of calibration (SEC), standard error of cross validation (SECV) and standard error of prediction (SEP) in the PLSR and Vis/NIRS models for pork quality parameters.

	Calibration					Validation		
	Factors	n	R^2	SEC	SECV	n	R^2	SEP
IMF (g/kg)	2	83	0.31	1.09	1,25	51	0.28	1.17
Moisture (g/kg)	3	83	0.47	1.07	1,25	51	0.18	1.73
WBSF (N/cm)	2	83	0.34	5.39	3,20	51	0.21	6.27

Barlocco et al. (2006)[6] developed a NIR spectroscopy model whose accuracy in cross validation for predicting IMF was 30% in the intact pork muscle and 87% in the homogenate muscle. To predict moisture these authors reported accuracy of 66% in intact and 90% in homogenate muscles.

Even though significant differences in the predictive models accuracy between intact and minced samples, the models accuracy found by these researchers for intact pork was much higher than that recorded in the present work, which shown as result 11% accuracy to predict the IMF and 31% to moisture in the cross validation models.

Another study tested the Vis/NIRS as a non-destructive method to predict quality characteristics of 411 pork loins and found a coefficient of determination (R^2) for calibration of 0.80 and 0.76 for moisture and IMF, respectively, and R^2 of 0.69 and 0.61 for moisture and IMF, respectively, in external validation database [1].

With regard to WBSF, the R^2 for calibration found in the present research is very close to the one found by Rodbotten et al. (2000) [12] who reported a R^2 for calibration of 0.35 for beef, and much higher than those reported by Chan et al. (2002) [1], who found a R^2 for calibration of 0.17 for intact pork.

Although the models have generated a R^2 for calibration and precision consistent with those reported in literature, the error associated to the estimative was considerably high, which decreases the accuracy of the technique to predict exact values of WBSF, indicating that the generated model is still weak to be applied in industrial line. Part of the explanation for this is the limited variation in tenderness in the present study compared to those in which NIRS and Vis/NIRS based models explained a large part of the variation in meat tenderness [4, 6, 12].

Even though the reliability to predict WBSF is considered moderate to low (below 60% - results reported in the literature [6, 13]), several authors highlight the ability of NIRS as a robust tool to predict tenderness classes, especially the extremes [13, 14, 15].

Several studies have reported that there is a difference in spectral line among samples of tender and tough meat, since tougher meat absorb more light than tender meats [3, 4, 12]. Typical spectral responses of the two pork tenderness classes are shown in Figure 1.

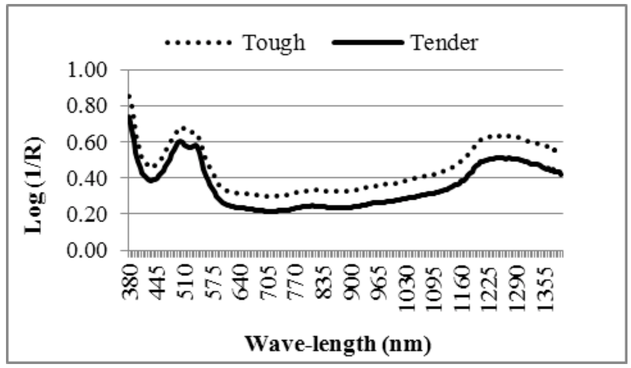

Figure 1: Measured spectral response of the two pork tenderness classes.

Based on predicted data (prediction test with external database) it was possible to build a classifier able to allocate the meat samples in two classes of tenderness: **tender,** when WBSF<45N; and **tough,** whenever WBSF≥45N.

The confusion matrix generated, the classifier precision, recall and the F-measure are shown in Tables 2 and 3, respectively.

In the present study, the Vis/NIR spectroscopy generated a classifier able to hit 80% (accuracy) of the samples' allocation (between tender and tough classes). Yet to classify samples as tender, the classifier has 95% success rate. This result is very close to the cited literature [3].

Table 2: The confusion matrix for a two-class classifier

		Predicted	
		Tender	Tough
Reference	Tender	36	2
	Tough	8	4

A previously review showed that NIR spectroscopy is a powerful tool to categorize meat and meat products into quality classes with classifiers which the percentage of correct allocation ranging from 80% to 100% in most cases [13]. Recently, Bonin (2012) [3] reported 93.3% accuracy classifying fresh beef samples between tender and tough, and 96.6% accuracy in classification of beef aged for seven days.

Table 3: Precision, recall and F-measure reported by the classifier.

	Precision	Recall	F-Measure
Tender	82%	95%	88%
Tough	67%	33%	44%

A classifier capable of grouping high tenderness pork loins with 95% accuracy is of great importance for the industry since it enables the creation of differentiated products lines, with high quality standard and high added value.

IV. CONCLUSION

In this study, the applicability of Vis/NIR spectroscopy to predict moisture, IMF and WBSF simultaneously and also the ability to classify pork into two tenderness classes was investigated. The PLSR and Vis/NIRS based models for moisture, IMF and WBSF yielded a moderate to low accuracy. However, Vis/NIR offer a promising way to classify pork *Longissimus* based on tenderness classes.. Further studies using samples of greater variability in these parameters are recommended.

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