Project Summary

Hyperspectral Imaging to Predict Sensory Beef Tenderness and Marbling Score

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Background
Beef tenderness should be incorporated into the USDA quality grading process if true, value-based marketing is to develop. Several studies have shown that most consumers can discern tenderness and a considerable portion of those consumers are willing to pay a premium for steaks that are "guaranteed tender." Hyperspectral imaging is a combination of video image analysis and near-infrared spectroscopy. Hyperspectral imaging works by measuring the relative intensity of light reflectance from an image across a broad spectrum of wavelengths on a pixel-by-pixel basis. This technique collects both muscle structure and biochemical information simultaneously.

The objectives for this project were to:

1. Develop a hyperspectral image database of 2-day and 14-day aged fresh beef steaks and collect reference slice shear force values.
2. Collect sensory tenderness scores on a subset of samples (n=300) that represents uniform distribution of shear force values across the range.
3. Develop and validate models to predict sensory tenderness scores using spectral and textural features extracted from hyperspectral images.
4. Predict marbling score from hyperspectral images.

Methodology
A hyperspectral imaging system consisting of an InGaAs digital video camera and a spectrograph was developed and a diffuse lighting chamber was designed. A photodiode was placed near a tungsten halogen lamp that provided feedback to a controller. A hemispherical dome was placed over the lamp and the inner surface was painted white to create a setup that provided uniform diffuse light over the steak. The hyperspectral camera was placed on a rack and pinion arrangement and acquired the image of the steak through a viewport in the hemisphere dome.

This type of push broom hyperspectral imaging system scans a line of object and disperses into two dimensional images where the horizontal and vertical dimensions correspond to spatial and spectral axes, respectively. A target with parallel straight lines of known length was placed in the sample plate and the working distance and focus of the camera was adjusted until the camera produced a sharp image. Pixel size was calculated by counting the number of pixels covering a known distance in the image.

Two beef ribeye steaks from selected carcasses were collected from four different regional beef packing plants, vacuum packaged and shipped to a central location. Before imaging, one of the steaks was removed from the vacuum package and was allowed to oxygenate for 30 minutes. Hyperspectral images of 759 beef ribeye steaks at 3 to 5 day post-mortem were collected. After imaging, steaks were aged 14 days and cooked for Slice Shear Force (SSF) tenderness determination. Based on the 14-day SSF values, samples were classified into three tenderness categories: tender (SSF=<21.0 kgf), intermediate (SSF=21.1 to 25.9 kgf), and tough (SSF>=26.0 kgf). Based on the 14-day SSF distribution, a subset of samples was selected for trained sensory panel analysis. Hyperspectral image files were exported to the Environment for Visualizing Images (ENVI) software (Research Systems Inc., Boulder, CO) for further image processing.

Findings

The relationship between the 14-day SSF values and 14-day sensory scores proved to be weak (R^2 = 0.29) illustrating the complexity of tenderness prediction. Trained personnel assigned marbling score and the variation in marbling score between carcasses was low. The bad pixels in InGaAs sensors translated to bad lines at various bands in the hyperspectral image. The bad lines were corrected by averaging two neighboring good lines.

Prediction of Sensory Score

The first step is to segment the beef steak from the background. Band 35 (λ=1078 nm) had a bimodal histogram and a simple thresholding segmented the beef steak from the background. A morphological opening operation was performed to remove any small particles in the background and a "fill" operation was performed to get a clean beef steak image. Principal component analysis (PCA) was carried out on the images to reduce dimension along spectra axis and to produce a bimodal histogram. A simple thresholding was done to identify the lean region and holes were filled to obtain *longissimus* muscle area. Subtraction of lean from *longissimus* muscle identified all marbling flecks. The longissimus muscle was segmented and the centroid of the muscle was located. A region-of-interest of size 64 x 128 pixels was selected in the *longissimus* muscle with centroid as the center.

Partial Least Square Regression

A mean spectrum from each ROI image was obtained by averaging the spectral signatures of all ROI pixels. The spectra were exported to Unscrambler® 9.6 (Camo Inc., Woodbridge, NJ), a chemometric modeling software. Partial least squares regression (PLSR) was conducted on the mean spectra by considering SSF as a dependant variable and loading vectors were obtained. By using the mean spectra of each sample, the within-sample variation was ignored and between-sample variation was used in determination of loading vectors. The loading vectors were exported to ENVI software and a PLSR image was created for each loading vector.

Of the PLSR images, four gray-level co-occurrence matrices at 256 gray levels with a distance value of 1 and angles 0°, 45°, 90°, and 135° were constructed for extracting image texture features. The textural features obtained from four different angles were then averaged to obtain rotation invariance results. Eight image textural features – namely mean, variance, homogeneity, contrast, dissimilarity, entropy, second moment and correlation – were extracted from each principal component (PC) and PLSR image.

Canonical Discriminant Model Development

The canonical discriminant algorithm was developed in SAS. The extracted textural features from each image were used for developing canonical discriminant algorithms with an option to use pooled covariate matrix and equal priors. As the aging period of the samples varied from 3 to 5 days, age was also included as a variable in canonical model development. The cross-validation procedure showed that the model classified steaks into three tenderness categories based on predicted aged beef tenderness with an accuracy of 60% (Table 1). By combining the intermediate samples with the tender samples, the overall accuracy of the method was 83.7%.

Table 1. Leave-one-out or cross-validation results of canonical discriminant model developed from partial least squares images with a quantization level of 256

Actual Categories[a]	Predicted Categories			Total
	Tender	Intermediate	Tough	
Tender	109	50	24	183
Intermediate	25	59	12	96
Tough	6	9	20	35
Total	140	118	56	314

[a]*Defined based on sensory tenderness scores.*

Prediction of Marbling Score

Ribeye area was separated and PC analysis was conducted to identify fat and lean pixels. Marbling area, no fat flecks, average fat fleck area and standard fat fleck area were calculated. All of these features were normalized with respect to *longissimus* muscle area. In addition, histogram features were extracted from *longissimus* muscle images of band 35 (1078 nm), band 74 (1208 nm), band 96 (1277 nm) and band 200 (1626 nm). In each band, features extracted were mean, standard deviation, skewness and kurtosis. A total of 100 features were extracted and 19 were selected and used in a linear regression model. The R^2 value of prediction was 0.63.

Implications

By combining the intermediate samples with the tender samples, the overall accuracy of the hyperspectral imaging system used in this study was 83.7%. Ribeye muscle area was traced and fat and lean pixels were identified. The regression model that was created predicted marbling score with and R^2 value of 0.63. These results appeared promising given that samples ranged in marbling score between Slight 40 and Small 90.

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