Ability of Near-Infrared Reflectance Spectroscopy to Predict Fat, Cholesterol, and Caloric Content of Fresh and Cooked Ground Beef

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Story in Brief

The objective of this study was to quantify fat, calories, and cholesterol content in fresh and cooked ground beef using near-infrared (NIR) spectroscopy. Weighed portions of USDA Select, peeled knuckles and 50:50 trim were ground, mixed, and formed into 0.33-lb patties with an approximate fat content of 5, 10, 15, 20, 25, 30, 35, and 40% (10 patties/fat level/replicate). Near-infrared reflectance (350 to 1,050 nm) was measured on the surface of patties from each fat group. Then, one-half of the patties were pan-fried to an internal temperature of 160°F, split longitudinally, and the inner surfaces of patties were scanned with the spectroradiometer. After scanning, fresh and cooked patties were freeze-dried, pulverized, and analyzed for fat, cholesterol, and caloric content. Partial least squares (PLS) regression analysis of the spectrum resulted in validation R^2 values (R_{Val}) for fat, calories, and cholesterol ranging from 0.91 to 0.98 for fresh ground beef and 0.73 to 0.93 for cooked ground beef. Overall predictability for the NIR region of the model had correlation coefficients ranging from 0.92 to 0.99 for fresh beef, and 0.78 to 0.96 in the cooked category. This study indicated that NIR spectroscopy could be a useful tool for quality monitoring in the beef industry.

Introduction

Approximately 50% of beef processed in the United States is consumed as ground beef. In the retail market ground beef is priced based on its fat content. Because excessive consumption of fat leads to elevated risks of obesity and cardiovascular diseases, fat, cholesterol, and caloric information have become important for both consumers and producers. Conventional techniques to quantify fat, calories, cholesterol, and moisture content in meat products are time consuming and expensive. In order to gain some economic advantage in price setting and to meet proposed legislative restrictions, the meat processing industry needs a rapid, on-line, non-invasive, and accurate tool to quantify nutrients in meat products.

Near-infrared (NIR) spectroscopy is widely used for sensory analysis and nutrient labeling of food products (Osborne, 1981). In an online experiment, Togerson et al. (2003) demonstrated the capability of NIR to predict fat, moisture and protein content of ground beef batches at an industrial scale. Additionally, NIR has been shown to accurately predict cooking losses and yields of cooked chicken patties (Chen and Marks, 1998). However, no attempts have been made to predict caloric and cholesterol content of ground meats, and, to date, all research has been conducted on fresh meat products. Therefore, the objective of this study was to use NIR to predict moisture, fat, cholesterol, and caloric content of both fresh and cooked ground beef.

Experimental Procedures

In three replicates, a total of 240 patties from batches of ground beef with 5, 10, 15, 20, 25, 30, 35, and 40% fat (10 patties per batch) were used in this experiment. A simple Pearson-square was used to determine the appropriate amounts of USDA Select peeled knuckles and 50:50 trim that would be needed to achieve the desired fat content of each batch of ground beef. Knuckles, with a pH of 5.5 to 5.6, were trimmed of any visible fat, and weighed proportions of fat and lean mixture were coarse ground in a Hobart grinder (Hobart Inc., Troy, Ohio) equipped with a 0.30-in plate. After mixing, coarse ground beef was ground again through a 0.125-in plate. Then, ground beef was formed into ten 0.33-lb patties with a Hobart patty machine (Hobart Inc., Troy, Ohio). To ensure quality control, the grinder and patty machine were thoroughly cleaned and sanitized between batches. The experiment was a completely randomized design with 240 samples (eight treatments with 10 patties per treatment replicated three times).

The surface of raw patties was scanned from 350 to 1,050 nm with an ASD Field Spec Pro (ASD Inc., Boulder, Colo.) spectroradiometer. Ten scans were collected at random from each patty. A 14.5 V, 50 W artificial tungsten halogen light (LowelPro, Lowel-Light Manufacturing Inc., Brooklyn, N.Y.) was used as the light source. The light was mounted at a distance of 1.2 m from the sample. The height of the light source and the position of the sensor were left undisturbed for the rest of the study (Figure 1).

After fresh patties were scanned, they were wrapped in a PVC film (O_2 transmission rate of 1400cc/m²/24h/atm) and stored at -4°F for later analyses. Half of all patties were thawed to room temperature, weighed, and pan-fried to an internal temperature of 160°F according to the cookery guidelines of Berry et al. (1995). A multichannel data logger (Doric Instruments, San Diego, Calif.), equipped with a hypodermic temperature probe, was used to monitor temperature at the center of the patties. Cooked patties were allowed to cool for 5 minutes, reweighed, and then split longitudinally to expose the inner surface the patties. Five NIR scans were recorded on the inner surface each patty half.

Moisture content of both fresh and cooked patties was measured using the freeze-drying method of Apple et al. (2001). Additionally, freeze-dried samples were pulverized and analyzed for fat, calories, and cholesterol according to AOAC (1990) procedures.

Partial least squares (PLS) regression is a bilinear modeling technique that extracts the most relevant information for prediction of chemical, physical, and sensory attributes of the sample, and selects factors that explain both response and prediction variation. In addition, it splits the spectra into spectral components, each component being a linear combination of wavelengths, which are used to predict a component or a property of interest. The NIR reflectance data and analytical variables (moisture, fat, calories, and cholesterol)

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were processed by PLS regression in CAMO Unscrambler (CAMO v8.0, Oslo, Norway). Predictive models were evaluated with NIR reflectance and analytical measurements, and three reflectance ranges – 400 to 700 nm (VIS), 701 to 1050 nm (NIR), and 400 to 1050 nm (VIS/NIR) – were used to evaluate predictability of the model. Furthermore, because color is considered a key factor in fat content, the effect of myoglobin peaks at 445 nm (deoxymyogoblin), 458 nm (metmyoglobin), and 560 nm (oxymyoglobin) were identified and correlated to the instrumental values. The model was validated with full-cross validation to ensure stability. With full-cross validation, each observation is removed one at a time from the sample set, and a new model calculation is performed where a predicted score is obtained for the sample removed. The procedure is repeated until all the samples are removed from the sample set once. Optimal number of principal components (linear functions of the original variables that contain the structured information in the data) was chosen to reduce complexity of the model. Correlation coefficients and model statistics were interpreted to further narrow the spectra with significant wavelengths. The "Jack-Knife" option in CAMO was used to select the important variables based on their loadings and scores. Thus, the model was optimized with fewer variables to obtain better stability.

Additionally, fat, moisture, cholesterol, and calorie data were analyzed as a completed randomized design using the GLM procedure of SAS (SAS Inst., Inc., Cary, N.C.), with fat level as the main effect included in the model. Least squares means were computed and separated statistically with the PDIFF option when the F-test was significant ($P \leq 0.05$). Also simple correlations among the dependent variables were generated with the correlation procedures of SAS.

Results and Discussion

Even though the actual fat content of fresh patties was much higher than the target levels, actual fat content increased as targeted levels increased from 5 to 40% (Table 1). Additionally caloric content increased ($P < 0.05$), whereas moisture and cholesterol content decreased ($P < 0.05$), as fat level increased in fresh ground beef patties. The range of analyzed nutrients in cooked patties was less variable, but fat, cholesterol, moisture, and caloric content responded similar to that of fresh patties.

Significant ($P < 0.01$) correlations were observed between fat, calories, and cholesterol for both fresh and cooked categories (Table 2). Pearson correlations of 0.99 and 0.98 were obtained between fat and calories, and -0.88 and -0.83 between calories and cholesterol for fresh and cooked categories, respectively. As expected, in both fresh and cooked ground beef, fat content was negatively correlated (-0.89 and -0.70, respectively) with moisture.

The absorbance spectra readily explained the spectral difference between fresh and cooked ground beef patties (Figure 2), and the amplitude difference among the varying fat levels (Figure 3). Results were similar to the on-line monitoring of ground beef fat content (Anderson and Walker, 2003).

The first phase of analysis was to correlate analytical data to first derivative NIR reflectance data (400 to 1,050 nm). The sample set was maintained separate for the fresh and cooked categories. Model output was satisfactory in predicting fat, calories and cholesterol in both categories, and R^2-values for the validation (R_{val}) ranged from 0.82 to 0.98 for both the categories (results not shown). The optimized model had fewer numbers of principal components (PC) as compared to the original model and raw reflectance regression model. However, the coefficient of determination decreased from 0.80 to 0.86 for cooked patty moisture and cholesterol content, respectively. Because NIR reflectance is more about structure and functional orientation of the basic functional groups, changes in response to cooking caused changes in NIR reflectance that are not well understood. As a result, the optical probe records all the changes, such as protein denaturation and rupture of fat pockets or cell membranes that do not correlate with reality in quantifying the actual nutrient content in the system.

In order to simplify the model, in a second analysis, the spectral range was separated into visible (VIS; 400 to 700 nm) and NIR (700 to 1,050 nm), and each range was processed separately with PLS (Table 3). In the VIS region, R_{val} of models predicting fat, calories, cholesterol, and moisture ranged from 0.93 to 0.98 for fresh and 0.73 to 0.84 for cooked ground beef, whereas, in the RIS region, the range in R_{val} values was 0.92 to 0.99 for fresh and 0.78 to 0.95 for cooked ground beef. Predictability in the VIS region was much lower for nutrients in cooked patties than that for raw patties, and models predicting cooked nutrient composition required more PC than when predicting fresh patty composition, regardless of spectra range.

Predictability with myoglobin peaks had R_{val} values from 0.79 to 0.98 for fresh ground beef, but R_{val} values for cooked ground beef were considerably lower, ranging from a low of 0.10 for cooked moisture content to a high of 0.58 for fat content (Table 4). A similar trend was also observed when myoglobin bands were used to predict fresh and cooked ground beef composition (results not shown).

The NIR and VIS regions were able to predict nutrient composition of fresh ground beef almost equally; however, the NIR region of the spectra explained more of the variation in fat, calories, and cholesterol content of cooked ground beef than VIS or individual selected wavelengths. Thus, NIR is able to predict the nutritional content and cholesterol content in both fresh and cooked ground beef. Results obtained from this study support NIR's predictability of chemical composition of raw ground beef and cooked beef. These results are similar to those obtained by Almendingen et al. (2000). Moreover, restricting the model to NIR region reduces equipment cost and computational time of the model, making it more practical for implementation at processing plants. However, the spectral range considered in this work is narrow compared to 400 to 2,500 nm that was used in most of the reported studies (Almendingen et al., 2000; Togerson et al., 2003).

Implications

To the authors' knowledge, this is the first study testing the possible use of near-infrared spectroscopy to predict the nutrient content of cooked meat products. More importantly, results of this experiment demonstrate that near-infrared spectroscopy has the potential to predict chemical composition of fresh and cooked ground beef with considerable variation in fat content.

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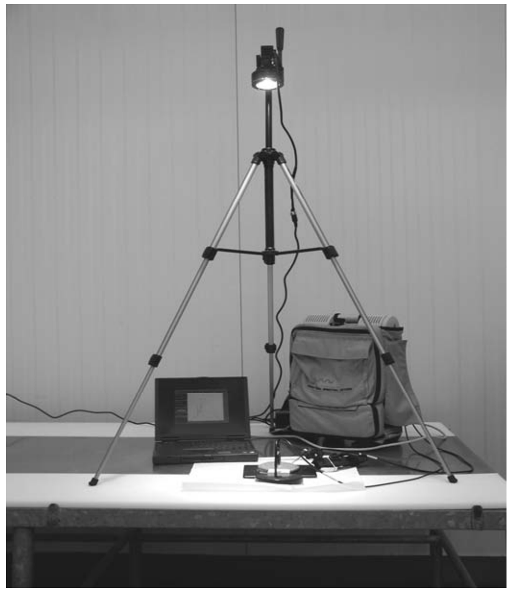

Fig. 1. Near-infrared experimental setup with artificial light source and hyper-spectral sensors.

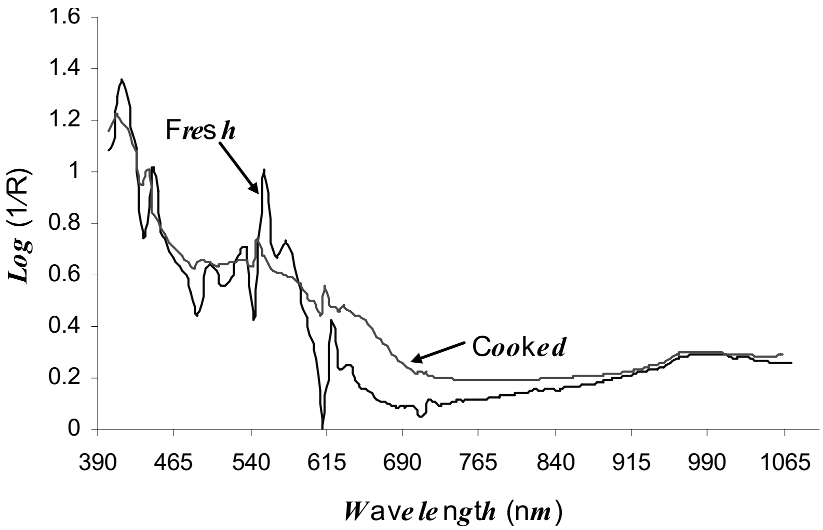

Fig. 2. Mean near-infrared absorbance spectra for fresh and cooked ground beef pooled across all fat levels.

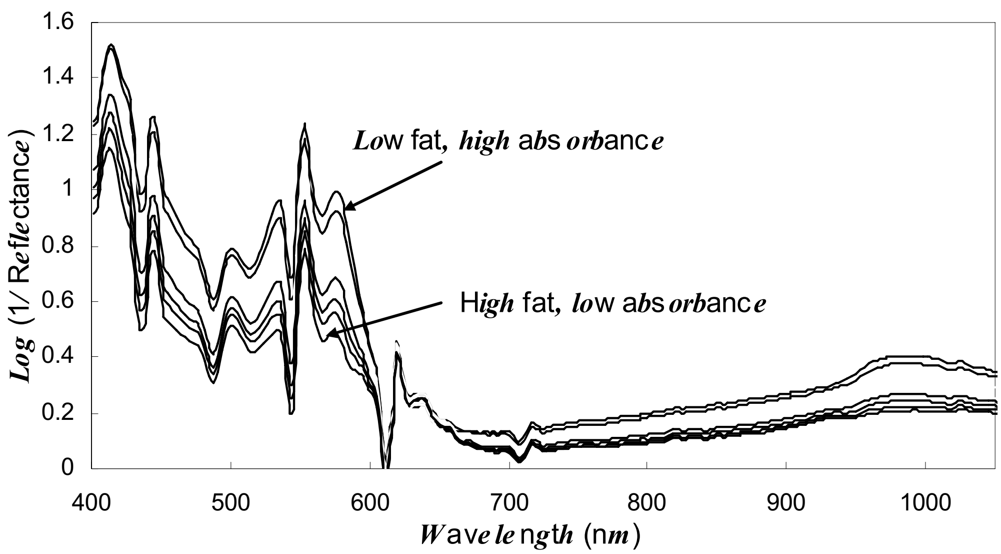

Fig. 3. Variation in absorption of fresh ground beef patties of varying fat content.

Table 1. Nutrient content (DM basis) of fresh and cooked ground beef patties stratified across approximated fat content.

	Fresh ground beef patties				Cooked ground beef patties			
Fat level, %	Fat, %	Calories, kcal	Cholesterol, mg/g	Moisture, %	Fat, %	Calories, kcal	Cholesterol, mg/g	Moisture, %
40	80.32^{a}	8.60^{a}	174.00^{e}	38.79^{g}	46.27^{a}	7.14^{a}	198.61^{cd}	39.24^{d}
35	75.83^{a}	8.33^{b}	176.57^{e}	43.33^{f}	44.73^{ab}	7.06^{ab}	200.53^{cd}	37.87^{d}
30	70.71^{b}	8.06^{c}	180.17^{de}	48.46^{e}	45.75^{ab}	7.14^{a}	192.19^{d}	39.52^{d}
25	60.32^{c}	7.73^{d}	198.06^{cd}	55.15^{d}	43.25^{b}	7.06^{ab}	205.40^{c}	43.94^{c}
20	55.03^{d}	7.41^{e}	195.65^{c}	58.74^{c}	40.38^{c}	6.94^{bc}	208.17^{c}	43.85^{c}
15	53.88^{d}	7.35^{e}	199.54^{c}	58.67^{c}	38.55^{c}	6.89^{c}	221.06^{b}	47.06^{b}
10	42.79^{e}	7.04^{f}	216.64^{b}	64.24^{b}	34.01^{d}	6.71^{d}	227.28^{b}	48.05^{b}
5	23.25^{f}	6.20^{g}	242.13^{a}	71.05^{a}	22.06^{e}	6.23^{e}	256.33^{a}	52.41^{a}

[a,b,c,d,e,f,g]Within a column, least squares means lacking a common superscript letter differ, $P < 0.05$.

Table 2. Pearson correlations for fat, calories, cholesterol, and moisture from fresh and cooked ground beef patties.

		Fresh ground beef patties				Cooked ground beef patties			
Category	Nutrient	Fat	Calories	Cholesterol	Moisture	Fat	Calories	Cholesterol	Moisture
Fresh	Fat	---	0.99	-0.89	-0.97	---	0.92	-0.83	-0.77
	Calories	---	---	-0.88	-0.97	---	---	-0.81	-0.75
	Cholesterol	---	---	---	0.83	---	---	---	0.66
	Moisture	---	---	---	---	---	---	---	---
Cooked	Fat	0.95	0.93	-0.88	-0.87	---	0.98	-0.85	-0.70
	Calories	---	0.90	-0.86	-0.83	---	---	-0.83	-0.66
	Cholesterol	---	---	0.86	0.74	---	---	---	0.74
	Moisture	---	---	---	0.72	---	---	---	---

Table 3. Partial least squares (PLS) statistics with visual (VIS; 400 to 700 nm) and near-infrared (NIR; 700 to 1,050 nm) spectra ranges for fresh and cooked ground beef patties.

		Fresh ground beef patties		Cooked ground beef patties	
Spectra	Nutrients	R_{val}[a]	PC[b]	R_{val}[a]	PC[b]
VIS	Fat	0.97	2	0.84	6
	Calories	0.97	2	0.84	6
	Cholesterol	0.93	5	0.75	5
	Moisture	0.98	2	0.73	6
NIR	Fat	0.97	1	0.95	5
	Calories	0.97	1	0.94	3
	Cholesterol	0.92	5	0.88	5
	Moisture	0.99	1	0.78	3

[a]Validation correlation coefficient that explains the percent variation accounted for by the number of principle components included in the model.
[b]Number of principle components (PC; partial linear functions of the original variables) used in the model.

Table 4. Validation correlation coefficients for partial least squares models including the myoglobin peaks from the visual spectra.

		Validation correlation coefficient (R_{val})			
Category	Myoglobin peaks[a]	Fat	Calories	Cholesterol	Moisture
Fresh	445 nm	0.94	0.95	0.79	0.98
	485 nm	0.92	0.91	0.80	0.93
	560 nm	0.93	0.94	0.79	0.98
Cooked	445 nm	0.58	0.53	0.49	0.50
	485 nm	0.13	0.32	0.08	0.27
	560 nm	0.27	0.22	0.02	0.01

[a]445 nm = deoxymyogoblin; 458 nm = metmyoglobin; and 560 nm = oxymyoglobin.