Visible/Near-Infrared Spectroscopy for Physical Characteristics of Cooked Chicken Patties

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ABSTRACT

Cooking loss and Kramer shear properties (yield force, yield deformation, and yield energy) of chicken patties were measured after various degrees of cooking. Cooking loss and yield deformation were related (R=0.91 and -0.76, respectively) to the integrated time-temperature history. In contrast, yield force and energy were well related (R=0.85 and 0.84, respectively) to endpoint temperature. Visible/near-infrared (NIR) calibrations were developed and validated for the physical characteristics. Among the tested properties, visible/NIR spectroscopy was most accurate in predicting cooking loss and yield force. Standard errors of prediction were 7.9 and 8.2% of the corresponding property range among samples.

Key Words: spectroscopy, thermal history, chicken patty, physical characteristics

INTRODUCTION

NEAR-INFRARED (NIR) SPECTROSCOPY

was first introduced in the 1960s to estimate the composition of foods and feeds (Ben-Gera and Norris, 1968). Common applications with meat include estimating moisture, fat, or protein content, pH, energy contents, hydroxyproline, and sodium chloride in meat products (Ben-Gera and Norris, 1968; Kruggel et al., 1981; Lanza, 1983; Valdes and Summers, 1986; Berg and Kolar, 1991; Mitsumoto et al., 1991).

NIR spectroscopy techniques have also been developed for estimating physical characteristics of meat products. Mitsumoto et al. (1991) tested NIR spectroscopy for quantifying Warner-Bratzler shear value of beef cuts, and obtained correlation coefficients of 0.8 to 0.83. Also using NIR spectroscopy, Hildrum et al. (1994) predicted sensory quality (hardness, tenderness, and juiciness) of beef cuts at three aging stages. Hardness and tenderness were predicted with correlation coefficients of 0.8 to 0.9, while juiciness was not well predicted. Ellekjaer et al. (1994) evaluated NIR spectroscopy as a potential means for determining the sensory quality of sausages (color, odors and flavors, juiciness and greasiness, firmness, and saltiness), and found that NIR spectroscopy mainly described the color and texture variations (juiciness and greasiness).

In food manufacturing systems, thermal processing of meat and poultry products serves to ensure microbial safety and create the desirable attributes and palatability of a cooked product. During thermal processing, considerable changes occur in color, flavor, tenderness, juiciness, and protein and fat status of the product (Baldwin and Cotterill, 1979). Such changes are caused by the combined effects of time and temperature (Lyon et al., 1975; Baldwin and Cotterill, 1979; Bertola et al., 1994). Specifically, in evaluating cooked ground turkey, both Wilkinson and Dawson (1966) and Tuomy et al. (1969) quasi-statically measured shear force with Kramer shear presses. Increased cooking temperature caused a decrease in shear force. However, neither study sought to mathematically describe the relationship between shear force and the combined time-temperature treatment.

Limited research has focused on NIR spectroscopy for evaluating thermally induced changes in meat products. Swatland (1983) measured reflectance (400–700 nm) of raw and cooked chicken muscles and observed spectral differences due to cooking. Using NIR spectroscopy, Ellekjaer and Isaksson (1992) estimated the endpoint temperature in previously heat-treated beef, and Chen and Marks (1997) estimated the integrated time-temperature history of heat-treated chicken patties. Both studies indicated that spectroscopic measurement to indicate previous thermal treatment was feasible and promising. However, no published work has specifically evaluated NIR spectroscopy for measurement of thermally induced quality changes in poultry products.

Therefore, the overall goal of this work was to develop NIR spectroscopy methods for evaluating the physical characteristics of chicken products after various degrees of cooking. Specific objectives were: (1) to relate the changes in physical characteristics of chicken patties to thermal history in convention cooking, and (2) to develop and evaluate visible/NIR calibrations for evaluating the physical characteristics of cooked patties.

MATERIALS & METHODS

Cooking procedures

Ground, formed, and frozen chicken breast patties (n=98, 6.2 cm dia, 1 cm thick) were acquired in one batch from a commercial processor. Prior to cooking, each patty was sealed in a polyethylene bag, thawed overnight at 3°C, and stabilized for about 2h at room temperature (~25°C).

The samples were cooked in a small convection oven ( Montgomery Ward Model 8287). Seven cooking air temperatures (135, 149, 163, 177, 191, 204, 218°C) and seven target endpoint center temperatures (50, 55, 60, 65, 70, 75, 80°C) were selected. The tests consisted of a full factorial design (i.e., 49 air/product temperature combinations).

For each of the 49 cooking conditions, duplicate samples with known weight were placed ~5 to 10 cm apart on a metal frame in the center of the oven. A thin-wire, Type-T thermocouple was inserted along the radial direction, halfway between the top and bottom of each sample, to the center of each sample. These thermocouples were connected to a data acquisition system outside the oven for real-time monitoring of the patty center temperature. Because the air temperature inside the oven was not perfectly uniform, the two samples were cooked with slightly different temperature histories. As soon as the slower heating patty reached the target endpoint temperature, both samples were immediately removed from the oven, weighed, and resaled in polyethylene bags. The bags were then immersed in running cold water (~11°C) for 10 to 20 min to rapidly cool the samples to room temperature prior to spectroscopic and physical measurements.

Spectroscopic measurements

The spectral properties of the treated samples were measured in a scanning monochromator (NIRSystmes 6500; Perstorp Analytical; Silver Springs, MD) installed with NIRS software (ISI International, 1995). A round sub-sample (3.8 cm diam) was cut from the center of each cooked patty, forced into a ring cup, presented to the instrument (via a sample transport module), and scanned 25 times at a resolution of 2 nm for an average visible/NIR (400 to 2500 nm) reflectance spectrum.
Visible/NIR Spectroscopy for Physical Characteristics

Physical measurements
Cooking loss was determined by weighing each sample before and after cooking. Loss is reported as a percent reduction in weight, on an initial weight basis.

Yield force, deformation, and energy were measured via a Kramer shear device (Lyon and Lyon, 1996). A Kramer shear press, with multiple blades and a cell, was attached to a compression testing machine (Instron model 1011, with Series IX control software; Instron Corp., Canton, MA). An intact sample (after thermal treatment and NIR scanning) was placed inside the cell and sheared with a crosshead speed of 100 mm/min. The yield force, deformation, and energy (integral of force vs deformation up to sample failure) were calculated from the force-deformation curve of each sample, where the yield point (i.e., failure) was defined as the point of maximum force.

Quantifying thermal history of cooked samples
The thermal history of each cooked sample was quantified by both the endpoint temperature $T_{\text{max}}$ (in °C) and the C value (in min) computed as:

$$C = \int_0^t [1 / (10^{(T_{\text{max}}-100)/z})] dt$$  \hfill (1)

where $Z$ (°C) is the temperature rise needed for a 10-fold increase in reaction rate for property changes, and $T$ is the sample center temperature (°C) at cooking time $t$ (min). The C value (Eq.1) describes the previous time-temperature (°C) at cooking time $t$ (min). The $C$ value (Eq.1) describes the previous time-temperature treatment with respect to cooking quality (Dagerskog, 1977; Sarkin, 1978; Holdsworth, 1985; Hallstrom et al., 1988); it can be explained as the equivalent process time at 100°C. Subsequently, the logarithm of the $C$ value was calculated to linearize the integrated value with respect to spectral data (Chen and Marks, 1997). The $Z$ value can vary from 24 to 30°C, depending on the specific quality factor (Dagerskog, 1977; Holdsworth, 1985). As in previous work (Chen and Marks, 1997), a $Z$ value of 26°C was used here to represent general cooking quality. While the $C$ value was an integrated time-temperature history, $T_{\text{max}}$ was the maximum center temperature for a given sample. In comparison, a greater $C$ value corresponded to a greater cooking temperature and/or a longer cooking time.

Calibration and prediction procedures
The 98 samples were divided into two sets, one for calibration and the other for prediction. For this division, principal component analysis (PCA) was performed on all the spectra to yield the Mahalanobis distance (or H distance) of each sample spectrum to the global spectra center of the samples. The samples were then ranked in terms of H distance.

Every third sample on the list was put into the validation set, and the remaining 65 samples comprised the calibration set.

The sample spectra were pretreated prior to calibration. A standard normal variate (SNV) technique was first used to scale each spectrum to a standard deviation of 1.0. This procedure was designed to provide a more linear fit between spectral data and physical characteristics (ISI International, 1995). Based on previous experience with homogeneous materials (Mitsumoto et al., 1991; Chen and Marks, 1997), modified partial least squares (MPLS) regression was then performed on the first derivative of the pretreated spectra and associated physical characteristics. This procedure reduced the interrelated spectral data to several independent principal components (PCs) or factors. Calibration equations were finally established in terms of the PCs (ISI International, 1995). Calibration accuracy was evaluated by the standard error of calibration (SEC), and prediction accuracy was evaluated by the standard error of prediction (SEP) (Marks and Workman, 1991).

RESULTS & DISCUSSION

Thermally induced physical property changes
Given the range of sample treatments, both the calibration and validation sets represented a wide range of physical characteristics (Table 1 and Fig. 1). Each of these characteristics (i.e., cooking loss, yield force, yield deformation, and yield energy) correlated fairly well with $T_{\text{max}}$ and $C$ value (Table 2). Cooking loss correlated better with the C value than with $T_{\text{max}}$. Yield force and energy correlated equally with $T_{\text{max}}$ and $C$, suggesting that endpoint temperature may be the major factor affecting yield force and energy. In contrast, yield deformation correlated slightly better with the C value than with $T_{\text{max}}$, which suggests that cooking time might also have considerable effect on yield deformation.

Qualitative inspection of the data revealed that relationships between thermal history and the physical characteristics did not appear to be linear (Fig. 2). The C value was positively and linearly related to cooking loss, but negatively and nonlinearly related to yield deformation. Endpoint temperature was related positively but nonlinearly to both yield force and energy, implying that a patty cooked to a higher endpoint temperature required more shear force and energy to reach sample failure. In general, change in yield deformation, force, and energy were less pronounced at log$_{10}C$ greater than -0.5 log$_{10}$ (min) or $T_{\text{max}}$ greater than 80°C. In a previous study (Murphy et al., 1998), the composition of this meat was determined to be ~95% (dry basis) protein, of which about 63% was myofibrillar protein, and 36% was sarcoplasmic protein. Thermal denaturation of these proteins occurred mainly in the temperature range 50 to 80°C, and therefore was probably a major

Table 1—Mean, range, and standard deviation (SD) of thermal history and physical characteristics for cooked chicken patties (n=98)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Mean</th>
<th>Range</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{max}}$ (°C)</td>
<td>69.5</td>
<td>50.3 to 98.1</td>
<td>12.0</td>
</tr>
<tr>
<td>log$<em>{10}C$ (log$</em>{10}$ (min))</td>
<td>-0.79</td>
<td>-1.79 to 0.53</td>
<td>0.55</td>
</tr>
<tr>
<td>Cooking loss (%)</td>
<td>10.8</td>
<td>4.08 to 18.58</td>
<td>3.66</td>
</tr>
<tr>
<td>Yield force (N)</td>
<td>263</td>
<td>60 to 430</td>
<td>104</td>
</tr>
<tr>
<td>Yield deformation (mm)</td>
<td>4.88</td>
<td>3.95 to 6.30</td>
<td>0.51</td>
</tr>
<tr>
<td>Yield energy (Nm)</td>
<td>0.55</td>
<td>0.13 to 0.96</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Fig.1—Two examples of distribution (A—thermal history; B—physical characteristics) among the calibration and validation sample sets.
factor causing the measured texture changes.

Physical properties in relation to visible/NIR spectra

Cooking loss, or cooking yield, is one of the most economically important parameters in commercial cooking systems. It results primarily from drip and evaporative loss of water during convection cooking. Although spectroscopic testing would be most directly sensitive to water content, we chose to analyze the cooking loss parameter (which reflects almost exclusively a reduction in water content), given that this is the most typically used parameter in commercial operations.

In general, with an increase in cooking loss and yield force, absorbance decreased in the entire visible/NIR range (Fig. 3). Variation of absorbance among samples was generally higher in the NIR (700–2500 nm) range than in the visible (400–700 nm) range (Fig. 4). According to Osborne et al. (1993) the peak near 1000 nm is mainly related to O-H bonds, the peak near 1200 nm to C-H bonds, and the peaks near 1450 nm and 2000 nm to both O-H and N-H bonds.

During thermal processing, a change in one physical characteristic is typically accompanied by and correlated with changes in other physical characteristics. Consequently, across the entire visible/NIR wavelength range, each physical characteristic had fairly consistent correlation with absorbance (Fig. 5). The negative correlation coefficients for the cooking loss and yield force versus absorbance agreed with previous observations (Fig. 3). Also, with the increase of yield energy or decrease of yield deformation, absorbance decreased.

Prediction of physical characteristics by visible/NIR spectra

Calibrations were developed and validated in three wavelength ranges, for each of the tested properties (Table 3). The best calibrations were selected on the basis of the SEP and coefficient of determination $R^2$. The best prediction of cooking loss was derived from the NIR (800 to 2500 nm) range, with an SEP:SEC ratio of 1.1 and an $R^2$ of 0.93. For yield force, the best prediction resulted from the entire visible/NIR (400 to 2500 nm) range, with an SEP:SEC ratio of 2.4 and an $R^2$ of 0.93. Likewise, the best prediction of yield deformation was also based on the entire visible/NIR range, with an SEP:SEC ratio of 0.95 and an $R^2$ of 0.69. However, the best prediction of yield energy occurred in the visible (400 to 700 nm) range, with an SEP:SEC ratio of 1.2 and an $R^2$ of 0.84.

In general, the developed calibration equations predicted the physical characteristics reasonably well (Fig. 6). The ratios of SEPs to the total ranges of each factor (Table 1) were 7.9% for cooking loss, 8.2% for yield force, 13.0% for yield deformation, and 10.9% for yield energy. Of the four physical characteristics investigated, the visible/NIR spectroscopy technique appeared to be most useful in evaluating cooking loss and yield force, and...
Visible/NIR Spectroscopy for Physical Characteristics

Table 3—Standard errors of calibration (SEC) and prediction (SEP) as well as corresponding coefficients of determination for physical characteristics at three wavelength ranges (best prediction is indicated by *)

<table>
<thead>
<tr>
<th></th>
<th>Calibration</th>
<th>Validation</th>
<th>Calibration</th>
<th>Validation</th>
<th>Calibration</th>
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<tbody>
<tr>
<td></td>
<td>400–700 nm</td>
<td>800–2500 nm</td>
<td>400–2500 nm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEC</td>
<td>R²</td>
<td>SEP</td>
<td>R²</td>
<td>SEC</td>
<td>R²</td>
</tr>
<tr>
<td>Cooking loss</td>
<td>0.99</td>
<td>0.92</td>
<td>1.37</td>
<td>0.89</td>
<td>1.02</td>
<td>0.90</td>
</tr>
<tr>
<td>Yield force</td>
<td>0.34</td>
<td>0.57</td>
<td>0.41</td>
<td>0.48</td>
<td>0.36</td>
<td>0.45</td>
</tr>
<tr>
<td>Yield deformation</td>
<td>0.99</td>
<td>0.92</td>
<td>1.37</td>
<td>0.89</td>
<td>1.02</td>
<td>0.90</td>
</tr>
<tr>
<td>Yield energy</td>
<td>0.08</td>
<td>0.87</td>
<td>0.09*</td>
<td>0.84</td>
<td>0.09</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Fig. 6—Predicted versus measured physical characteristics. SEP=standard error of prediction.

CONCLUSIONS

Cooking loss and yield deformation were best related to the integrated time-temperature history (C value), while yield force and energy were best related to the endpoint temperature T_max. These physical changes were most likely due to mass loss and protein denaturation in patties during thermal processing. Spectral reflectance was sensitive to such physical changes across the entire visible/NIR wavelength range (400 to 2500 nm). Among the tested properties, visible/NIR spectroscopy appeared to have the best potential for evaluating cooking loss and yield force. The results suggest that spectroscopic techniques might be used for rapid monitoring of physical characteristics in thermal processing. However, further work is required to verify the potential of visible/NIR spectroscopy for other poultry products. Additionally, environmental and processing variables need to be studied to reduce the prediction error.

REFERENCES


Ms received 6/19/97; revised 10/28/97; accepted 11/1/97.

This project was supported by funding from the Arkansas Science and Technology Authority. The chicken patties were provided by Tyson Food, Inc. (Springdale, AR).