Measurement of water-holding capacity in raw and freeze-dried broiler breast meat with visible and near-infrared spectroscopy

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ABSTRACT The feasibility of using visible/near-infrared spectroscopy (vis/NIR) to segregate broiler breast fillets by water-holding capacity (WHC) was determined. Broiler breast fillets (n = 72) were selected from a commercial deboning line based on visual color assessment. Meat color (L*a*b*), pH (2 and 24 h), drip loss, and salt-induced water uptake were measured. Reflectance measurements were recorded from 400 to 2,500 nm in both raw and freeze-dried breast meat samples. Raw and freeze-dried samples had similar spectra in the visible region (400–750 nm), but the freeze-dried samples exhibited numerous bands in the NIR region (750–2,500 nm) corresponding to muscle proteins and lipids that were not observed in the NIR spectra of the raw samples. Linear discriminate analyses were used to classify fillets as high-WHC or low-WHC according to predicted meat quality characteristics. Using the visible spectra (400–750 nm), fillets could be correctly classified into high-WHC and low-WHC groups based on drip loss and salt-induced water uptake with 88 to 92% accuracy in raw samples and 79 to 86% accuracy in freeze-dried samples. Using the NIR spectra (750–2,500 nm), fillets could be correctly classified into high-WHC and low-WHC groups with 74 to 76% accuracy in raw samples and 85 to 86% accuracy in freeze-dried samples. Thus, freeze-drying enhanced the accuracy of WHC classification using the NIR portion of the spectra. Data from this study demonstrate the potential for utilizing vis/NIR spectroscopy as a method for classifying broiler breast meat according to WHC.

Key words: broiler breast meat, freeze-dried, meat quality, visible-near infrared spectroscopy, water-holding capacity

INTRODUCTION

As the consumption of poultry meat continues to grow (National Chicken Council, 2013), more emphasis is placed on fresh meat quality traits. Water-holding capacity (WHC) refers to the ability of meat to retain inherent or added water through processing and storage. The WHC of fresh broiler meat is important because it influences product yields for processors and sensory quality for consumers. Numerous methodologies have been developed for measuring WHC, but all fall into 3 basic categories: measuring fluid weight loss with the application of no external force, with the application of a mechanical force, or with the application of a thermal force (Honikel, 2009). These methods are both time consuming and destructive to the product. Measurement of WHC in fresh meat is further complicated by the fact that WHC changes with post-mortem storage, processing, and preparation of meat. Thus, there is a need to develop a rapid, nondestructive method for measuring WHC in fresh poultry meat that can be used as a basis for detecting poor WHC and segregating product in a commercial setting.

Visible/near-infrared spectroscopy (vis/NIR) is an analytical technique being researched for its potential use in the muscle foods industry (as reviewed by Weeranantananaphan et al., 2011). It is based on the principle that meat varies widely in its chemical composition and that different chemical bonds absorb or emit light differently over a range of wavelengths (400–2,500 nm). The development of spectroscopic techniques for assessing meat quality traits would be of interest to the poultry industry because of their potential for rapid, nondestructive, and accurate measurements. Although much research has been conducted on the use of vis/NIR spectroscopy to predict the chemical composition of chicken meat (Renden et al., 1986; Valdes and Summers, 1986; Cozzolino et al., 1996; Abeni and Bergoglio, 2001; Windham et al., 2003; Berzaghi et al., 2005; Kadim et al., 2005; McDevitt et al., 2005), relatively little has been done on its application in measuring meat quality traits in fresh chicken meat. Several stud-
ies have investigated the application of vis/NIR spectroscopy for determining meat color, sensory characteristics, and texture (shear force) in broiler breast meat (Liu et al., 2004; Meullenet et al., 2004; De Marchi et al., 2011). Only one study, however, has examined the potential for using vis/NIR spectroscopy for predicting WHC in broiler breast meat (Samuel et al., 2011). In this study, however, WHC was measured on muscle samples that were previously subjected to freezing and thawing, which is known to affect WHC.

Water-holding capacity is a complex meat quality trait dependent upon both the chemical and structural characteristics of the muscle. During the transformation of muscle to meat, protein denaturation and degradation influence the intricate structure of muscle and the ability of meat to bind water. The NIR region of the electromagnetic spectrum (750–2,500 nm) provides valuable information on chemical bonds characteristic of proteins that could potentially be useful for predicting WHC. Because muscle is approximately 75% water, however, the NIR region of the spectra from meat is often dominated by broad bands corresponding to water. Lesser bands are more difficult to discern. It is hypothesized that the ability to measure WHC in fresh chicken meat using vis/NIR spectroscopy can be improved by freeze-drying the meat before analysis. Thus, the objectives of this study were to compare the vis/NIR spectra of raw and freeze-dried breast muscle and to determine the feasibility of using vis/NIR spectroscopy to segregate broiler breast fillets according to WHC.

**MATERIALS AND METHODS**

**Broiler Breast Collection and Sample Processing**

Boneless, skinless broiler breast fillets (n = 72) were collected on 3 separate trial days from a commercial broiler processing plant which used postmortem electrical stimulation to accelerate rigor onset. Samples were selected from a postchilling deboning line at 1.5 h postmortem based on visual color assessment (pale or dark) to yield a population of fillets with divergent WHC characteristics. The fillets were placed on ice and transported to the laboratory (15 min). Left and right fillets were separated, trimmed of visible fat and connective tissue, and individually weighed. Right fillets were used for pH, color, and drip loss measurements. At approximately 4 h postmortem, left fillets were individually chopped for 30 s in a food processor (HCS06, Black & Decker Corp., Towson, MD). A portion of each chopped sample was used for measuring salt-induced water uptake and vis/NIR spectra on raw meat. The remaining portion of each chopped sample was frozen at −80°C, freeze-dried (VirTis Freezemobile 25EL, SP Industries Inc., Warminster, PA) for 24 h, and then further ground using a coffee grinder for the measurement of vis/NIR spectra on freeze-dried meat. Moisture content of both raw and freeze-dried samples was measured in duplicate by drying 5 g in aluminum pans at 100°C for 18 h (AOAC, 1990).

**Initial pH and Color Measurements**

Duplicate pH measurements were made at 2 h postmortem with a Hach H280GB pH meter and a PH57-SS spear-tipped pH probe (Hach Inc., Loveland, CO) inserted into the cranial end of the intact fillets. Color measurements were made on the dorsal side of the fillets with a Minolta Spectrophotometer CM-700d (Konica Minolta Inc., Ramsey, NJ). Measurements were recorded as the average of 3 readings and expressed in terms of CIE values for lightness (L*), redness (a*), and yellowness (b*).

**Drip Loss and Ultimate pH Measurements**

Drip loss was measured according to the modified procedure of Honikel (1998). At approximately 6 h postmortem, a 40-g sample was removed from the central portion of the fillet using a coring device, weighed, placed on a mesh screen in a covered plastic container, and stored at 4°C. The sample was reweighed at d 2 and 7 postmortem, and drip loss (%) was calculated as [100 × (weight of drip/initial sample weight)]. The remaining portion of the fillet was minced with a knife and stored at 4°C until 24 h postmortem. Duplicate 1-g samples were homogenized with 10 mL of cold, deionized water with a tissue homogenizer (Powermax AHS 250, ProScientific Inc., Oxford, CT), and pH was measured in the slurry (Stewart et al., 1984).

**Salt-Induced Water Uptake Measurements**

Salt-induced water uptake was measured at 6 and 24 h postmortem according to the modified procedure of Wardlaw et al. (1973). Duplicate 10-g samples of the chopped muscle samples were mixed with 15 mL of cold 0.6 M NaCl solution in 50-mL centrifuge tubes. Samples were vortex mixed for 1 min, stored at 4°C for 15 min, and then centrifuged at 7,000 × g for 15 min at 4°C. The excess liquid was decanted and the sample reweighed. Salt-induced water uptake was expressed as the percentage of weight gained by the pellet [100 × (final weight − initial weight)/initial weight].

**Vis/NIR Spectroscopy Measurements**

The vis/NIR spectroscopy spectra were collected using a Foss XDS scanning monochrometer (FOSS North America, Eden Prairie, MN) in the diffuse reflection mode. Each reflectance spectrum was an average of 32 scans with 2 nm resolution over the range of 400 to 2,500 nm. The samples were contained in a 38-mm diameter sample cup with a quartz window, which was thoroughly cleaned between samples.
The vis/NIR spectra were analyzed using The Unscrambler software (Camo Software Inc., Woodbridge, NJ). The classification of fillets into 2 classes was performed by linear discriminate analysis using Mahalanobis distance. Fillets were segregated into 2 categories based on meat quality and physical measurements. For example, fillets with L* values above 54 were placed in one category, and those below 54 were placed in the second category. The spectra were compared using the unprocessed data, the first derivative with Savitzky Golay filter and 5 point smoothing, and the second derivative with Savitzky Golay filter and 5 point smoothing. Discriminating peaks were chosen based on a visual analysis of variability between the classes of samples. Five, 4, and 6 peaks were chosen in the visible range for the unprocessed (422, 492, 544, 550, and 576 nm), first derivative (532, 554, 570, and 590 nm), and second derivative (442, 452, 544, 562, 580, and 596 nm) spectra, respectively. The same peaks were used for the analyses of both the raw and freeze-dried samples in the visible region because of the similarity in both sets of spectra. Due to differences in the spectra of the raw and freeze-dried samples in the NIR region, different peaks were chosen for analyses of the 2 treatments. For the raw samples, the NIR peaks chosen were 978, 1,190, 1,348, 1,450, 1,784, and 1,920 nm for the unprocessed spectra, 950, 1,140, 1,386, 1,756, and 1,872 nm for the first derivative, and 924, 960, 1,378, 1,400, 1,854, and 1,890 nm for the second derivatives. For the freeze-dried samples, the NIR peaks chosen were 1,510, 1,690, 1,740, 1,976, 2,060, 2,180, 2,300, and 2,350 nm for the unprocessed spectra, 1,404, 1,486, 1,616, 1,680, 1,966, and 2,144 nm for the first derivative, and 1,518, 1,690, 1,738, 1,474, 1,492, 1,932, 1,960, and 2,310 nm for the second derivatives. The linear discriminate analysis was used assuming equal prior probabilities and the samples were predicted into 1 of the 2 classes based on the Mahalanobis distance calculated using the peaks described above. The classification of the fillets according to meat quality and physical measurements was then compared with the actual classification for accuracy of prediction using the spectral information.

**RESULTS AND DISCUSSION**

**Meat Quality Characteristics of Broiler Breast Fillets**

The overall objective of this study was to test the potential for using vis/NIR spectroscopy to classify broiler breast fillets according to WHC. To achieve this, fillets varying widely in WHC were desired. Because WHC in broiler breast fillets strongly correlates to meat L* values (Qiao et al., 2001), the fillets in this study were selected from a commercial deboning line based on visual color assessments to obtain fillets with relatively high and low WHC. The physical character-istics and meat quality traits of the broiler breast fillets used in this study are shown in Table 1. As expected, low-WHC fillets had higher L* values and lower pH at 2 and 24 h postmortem than high-WHC fillets. In this study, WHC of the fillets was measured by 2 different methods: drip loss and salt-induced water uptake. Drip loss measurements indicate the potential for fillets to lose moisture as exudate during raw meat storage. Salt-induced water uptake measurements indicate the potential for fillets to absorb and retain added water in moisture-enhanced products. Fillets designated as low-WHC by initial color assessment exhibited on average greater drip loss and lower salt-induced water uptake than high-WHC fillets. The relationships between the WHC, color, and pH measurements were determined by correlation analysis (Table 2). Lightness (L*) values were highly correlated to pH24h, and the various WHC measurements (|r| = 0.71–0.83). Muscle pH at 24 h postmortem exhibited higher correlations to WHC measurements than pH at 2 h. Measures of drip loss and salt-induced water uptake were closely related. Overall, it was concluded that samples in this study varied sufficiently in WHC traits to adequately test the potential for using vis/NIR spectroscopy for classifying broiler breast fillets based on meat quality.

**Vis/NIR Spectra of Raw and Freeze-Dried Broiler Breast Fillets**

Figure 1 shows the vis/NIR spectra of the raw samples from high-WHC and low-WHC broiler breast fillets. In the visible region (400–750 nm), 3 distinguishable bands at 430, 492, and 560 nm were observed in both types of fillets. Based on past research (Liu and Chen, 2000), it is likely that these bands correspond to deoxymyoglobin (430 nm), metmyoglobin (492 nm), and oxymyoglobin (550 nm). In the near-infrared region (750–2,500 nm), 5 distinguishable bands at 980, 1,190, 1,460, 1,790, and 1,930 nm were observed in both high-WHC and low-WHC fillets. The bands at 980, 1,460, and 1,930 nm were likely due to water present in the muscle samples. Specifically, these bands correspond to the second overtone of the OH-stretching mode of water (980 nm), the first overtone of the OH-stretching mode of water (1,460 nm), and a stretching and bend combination band of water (1,930 nm; Osborne et al., 1993; Liu and Chen, 2000). The 1,190 and 1,790 nm bands likely correspond to the overtones of the CH-stretching modes from lipid molecules within the muscle tissue.

Figure 2 shows the vis/NIR spectra of the muscle samples from high-WHC and low-WHC breast fillets after they had been freeze-dried. Similar to the raw samples, the freeze-dried samples exhibited 3 bands within the visible region of the spectra in both types of fillets. The freeze-dried samples, however, exhibited 11 distinguishable bands within the NIR region of the spectra. The bands at 908 and 1,190 nm likely correspond to the third and second overtones of CH bonds.
The 1,512, 1,690, 1,740, 1,980, 2,056, 2,178, and 2,300 bands are likely due to chemical bonds associated with the proteins within the muscle samples. The 2,350 and 2,470 nm bands likely represent combination bands associated with the lipids in the muscle samples (Workman and Weyer, 2008).

Although there was much sample-to-sample variation in the vis/NIR spectra of the raw and freeze-dried samples, the average spectra of the samples obtained from high-WHC and low-WHC fillets exhibited similar overall banding patterns based on the unprocessed spectra data (Figures 1 and 2). The first derivative of the spectra data, however, more clearly revealed differences between the 2 types of fillets. The first derivatives of the spectra data from the visible region (400–750 nm) of the raw and freeze-dried samples are shown in Figures 3 and 4. In the raw muscle (Figure 3), high-WHC fillets exhibited greater signals at 405, 430, 530, 560, and 590 nm than low-WHC fillets. In the freeze-dried muscle (Figure 4), however, high-WHC fillets exhibited greater signals at 590 and lesser signals at 430 and 735 nm than low-WHC fillets. These results were not surprising given that the visible region of the spectra corresponds to muscle pigments (oxy-, deoxy-, and metmyoglobin), and the samples were initially screened by meat color attributes. The first derivatives of the spectra data from the visible region (400–750 nm) of the raw and freeze-dried samples are shown in Figures 5 and 6. In the raw muscle samples, the differences between the 2 types of fillets were minor with the low-WHC fillets exhibiting slightly greater signals at 1,380, 1,530, and 1,865 nm than the high-WHC fillets (Figure 5). In the freeze-dried samples, however, the first derivative spectra differences between the high-WHC and low-WHC fillets were substantial in the NIR region with significant signal differences for almost every observed band (Figure 6). Overall, differences between the high-WHC and low-WHC fillets were greater in the visible region of the spectra in raw samples and greater in the NIR region in freeze-dried samples.

The freeze-drying process in this study diminished the moisture content of the muscle samples from 75 to 76% down to approximately 3 to 4% (Table 1). As expected, this had a tremendous impact on the spectra exhibited by the muscle samples. Whereas the visible region of the spectra was similar between freeze-dried and raw samples, the NIR region of the spectra (750–2,500 nm) of freeze-dried samples exhibited more numerous bands than the raw samples (Figures 1 and 2). With freeze-drying of samples, large bands within the NIR region of the spectra caused by water diminished, and bands corresponding to proteins and lipids that were previously masked became readily apparent. It is speculated that these revealed bands may yield information on WHC. Because WHC is not closely related to the overall moisture content of muscle and is more influenced by the membrane and structural integrity of the muscle cells in the tissue, the potential for using the

Table 1. Physical traits and meat quality characteristics of broiler breast fillets1

<table>
<thead>
<tr>
<th>Trait</th>
<th>High-WHC fillets (n = 36)</th>
<th>Low-WHC fillets (n = 36)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Fillet size (g)</td>
<td>149.0</td>
<td>34.5</td>
</tr>
<tr>
<td>Moisture content %: raw</td>
<td>75.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Moisture content %: freeze-dried</td>
<td>2.9</td>
<td>2.2</td>
</tr>
<tr>
<td>L*</td>
<td>46.3</td>
<td>2.5</td>
</tr>
<tr>
<td>a*</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>b*</td>
<td>9.2</td>
<td>1.3</td>
</tr>
<tr>
<td>pH2h</td>
<td>6.17</td>
<td>0.37</td>
</tr>
<tr>
<td>pH24h</td>
<td>6.20</td>
<td>0.19</td>
</tr>
<tr>
<td>Drip loss %: d 2</td>
<td>0.47</td>
<td>0.19</td>
</tr>
<tr>
<td>Drip loss %: d 7</td>
<td>1.56</td>
<td>0.87</td>
</tr>
<tr>
<td>Salt-induced water uptake %: 6 h</td>
<td>62.9</td>
<td>35.3</td>
</tr>
<tr>
<td>Salt-induced water uptake %: 24 h</td>
<td>84.3</td>
<td>38.5</td>
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</table>

<table>
<thead>
<tr>
<th>Trait</th>
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<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHC = water-holding capacity. pH2h = pH at 2 h; pH24h = pH at 24 h.</td>
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</tbody>
</table>

Table 2. Pearson correlation coefficients of meat quality characteristics of broiler breast fillets (n = 72)1

<table>
<thead>
<tr>
<th>Trait</th>
<th>L*</th>
<th>pH2h</th>
<th>pH24h</th>
<th>DL2d</th>
<th>DL7d</th>
<th>WU6h</th>
<th>WU24h</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH2h</td>
<td>−0.36*</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>pH24h</td>
<td>−0.82***</td>
<td>0.55***</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>DL2d</td>
<td>0.85***</td>
<td>−0.35*</td>
<td>−0.77***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DL7d</td>
<td>0.77***</td>
<td>−0.47**</td>
<td>−0.72***</td>
<td>0.90***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WU6h</td>
<td>−0.71***</td>
<td>0.67***</td>
<td>0.77***</td>
<td>−0.62***</td>
<td>−0.74***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WU24h</td>
<td>−0.72***</td>
<td>0.64***</td>
<td>0.76***</td>
<td>−0.63***</td>
<td>−0.74***</td>
<td>0.96***</td>
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</table>

<table>
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<tr>
<th>Trait</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHC = water-holding capacity. pH2h = pH at 2 h; pH24h = pH at 24 h. DL2d = drip loss % at 2 d; DL7d = drip loss % at 7 d. WU6h = salt-induced water uptake % at 6 h; WU24h = salt-induced water uptake % at 24 h.</td>
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*P < 0.01, **P < 0.001, ***P < 0.0001.
Figure 1. Average visible/near-infrared spectra (400–2,500 nm) of raw meat samples from high water-holding capacity (WHC) and low WHC broiler breast fillets.

Figure 2. Average visible/near-infrared spectra (400–2,500 nm) of freeze-dried meat samples from high water-holding capacity (WHC) and low WHC broiler breast fillets.

Figure 3. Average of the first derivative of the visible spectra (400–750 nm) of raw meat samples from high water-holding capacity (WHC) and low WHC broiler breast fillets.

Figure 4. Average of the first derivative of the visible spectra (400–750 nm) of freeze-dried meat samples from high water-holding capacity (WHC) and low WHC broiler breast fillets.

Figure 5. Average of the first derivative of the near-infrared spectra (750–2,500 nm) of raw meat samples from high water-holding capacity (WHC) and low WHC broiler breast fillets.

Figure 6. Average of the first derivative of the near-infrared spectra (750–2,500 nm) of freeze-dried meat samples from high water-holding capacity (WHC) and low WHC broiler breast fillets.
NIR portion of the spectra for predicting WHC may be enhanced by freeze-drying. This is supported by the observation that NIR region spectra differences between low-WHC and high-WHC fillets were greater in freeze-dried than raw samples (Figure 5 and 6).

**Classification of Broiler Breast Fillets Based on WHC Using Vis/NIR Spectra**

Linear discriminate analysis was used to determine if the spectra differences observed in this study could be used to classify fillets based on meat quality traits. Breast fillets were classified as high-WHC or low-WHC according to predicted quality characteristics. Classification analysis was conducted on the unprocessed vis/NIR spectra data as well as the first and second derivatives of the data. Models were initially developed based on the entire vis/NIR spectra (data not shown); however, it was determined that more accurate classifications could be made by analyzing the visible and the NIR spectra separately.

Table 3 shows the visible spectra (400–750 nm) classification analyses that exhibited the greatest average percentage of correctly classified fillets for each meat quality trait. For L*, pH2h, and the various measures of WHC, a higher proportion of fillets were correctly classified using the visible spectra data from the raw muscle samples compared with the freeze-dried samples. For pH2h, however, the effect of freeze drying on the classification accuracy was dependent upon the type of fillet. Given that fillets were initially selected based on meat color and that the visible region of the spectra reflects muscle pigments, the high level of correct classification based on L* was expected. The visible spectra exhibited a stronger ability to correctly classify fillets based on pH at 24 h postmortem compared with pH at 2 h. A greater percentage of fillets were correctly classified by d 2 drip loss than by d 7 drip loss. A slightly higher proportion of fillets were correctly classified according to salt-induced water uptake measured at 24 h compared with 6 h postmortem using the visible spectra. The ability of the visible spectra to correctly segregate fillets based on drip loss and salt-induced water uptake was similar. In both raw and freeze-dried samples, a greater percentage of the high-WHC fillets was correctly classified than the low-WHC fillets for both WHC measurements.

Table 4 shows the NIR spectra (750–2,500 nm) classification analyses that exhibited the greatest average percentage of correctly classified fillets for each meat quality trait. In both raw and freeze-dried samples, classification accuracy for segregation by L* values was greater in low-WHC compared with high-WHC fillets. For pH2h segregation in raw samples, classification accuracy was greater in the low-WHC fillets than the high-WHC fillets, whereas the reverse was observed in the freeze-dried samples. With segregation of samples by pH2h, however, classification accuracy was greater in the low-WHC fillets for both raw and freeze-dried samples. For classification by drip loss and salt-induced water uptake measurements, accuracy was consistently greater in freeze-dried versus raw samples regardless of fillet type. In both raw and freeze-dried samples, classification by salt-induced water uptake was more accurate in low-WHC fillets.

Data from this study demonstrated that freeze-drying muscle samples enhanced the ability to correctly segregate broiler breast fillets based on WHC measurements using the NIR region of the spectra. Although impractical from a commercial standpoint, removing water from the muscle samples unveiled more information on muscle proteins, which enabled a more accurate WHC classification. The level of classification accuracy with freeze-dried samples using the NIR spectra (85–86%),
however, was still not as high as classifying raw samples using the visible region of the spectra (88–92%). With the exception of pH2h, the greatest classification accuracy for each meat quality trait was achieved using the raw samples and the visible region of the spectra.

The WHC classification accuracies observed in the current study (74–92% correct) are consistent with past research, which suggests that WHC cannot be predicted in fresh meat to the same degree of accuracy as the chemical composition of the meat (as reviewed by Weeranantanaphan et al., 2011). Studies that used vis/NIR spectroscopy to predict WHC in beef found R2 values ranging from 0.20 to 0.89 (Leroy et al., 2003; Geesink et al., 2006; Prevolnik et al., 2009, 2010). In pork, where inferior WHC is much more prevalent and problematic than in beef, reported vis/NIR prediction models for WHC have ranged in R2 values from 0.06 to 0.56 (Brendum et al., 2000; Geesink et al., 2003; Hoving-Bolink et al., 2005; Candek-Potokar et al., 2006; Savenije et al., 2006; Prevolnik et al., 2009, 2010). In breast and thigh muscles from guinea fowl, an R2 value of 0.39 was observed for predicting WHC (Tejerina et al., 2009). The variable results of these past studies were likely due to differences in muscle sample preparation (intact versus homogenized tissue), WHC measurements, and the portion of the spectra used. The difficulties in predicting WHC with a high level of accuracy using vis/NIR spectroscopy are likely due to the complexity of factors that control WHC. The ability of meat to retain moisture is not dependent on a particular component of the muscle but rather on the intricate interaction between the physicochemical, biochemical, and structural traits of the muscle tissue.

The moderate level of classification accuracy (88–92% correct, raw samples, visible spectra) achieved with the divergent set of breast fillets used in this study suggests that vis/NIR spectroscopy is likely more suited to segregating breast fillets into groups based on set WHC criteria rather than as a direct measurement of WHC at a quality assurance level of accuracy. It is likely that adjusting segregation criteria for a particular commercial application may further enhance the degree of classification accuracy. The results of this study may have been influenced by the time postmortem at which the spectra were measured (8–10 h postmortem). As broiler breast muscle undergoes numerous changes beginning at bird slaughter and throughout postmortem storage, it is possible that particular postmortem times may be optimal for spectral-based prediction of meat quality traits. Although this study demonstrates the potential for using vis/NIR spectroscopy as a method for segregating broiler breast meat based on WHC, further research on a broad range of breast fillets at different times postmortem is warranted to determine its full potential for commercial application.

### ACKNOWLEDGMENTS

The authors thank Elizabeth Barton, Andrew Ross, Taylor Kronn, and Candace Betts (USDA-Agricultural Research Service) for their technical assistance in this research.

#### Table 4. Classification of raw and freeze-dried broiler breast fillet samples from near-infrared spectrum (750–2,500 nm) based on predicted/measured meat quality values1

<table>
<thead>
<tr>
<th>Trait</th>
<th>Wavelength</th>
<th>WHC2</th>
<th>WHC3</th>
<th>Average</th>
<th>WHC2</th>
<th>WHC3</th>
<th>Average</th>
</tr>
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<tbody>
<tr>
<td>L*</td>
<td>978, 1,190, 1,348, 1,450, 1,784, 1,920nm</td>
<td>80.6</td>
<td>91.7</td>
<td>86.1</td>
<td>79.0</td>
<td>84.7</td>
<td>84.7</td>
</tr>
<tr>
<td>pH2h</td>
<td>924, 960, 1,378, 1,400, 1,854, 1,890nm†</td>
<td>75.0</td>
<td>83.3</td>
<td>79.2</td>
<td>91.7</td>
<td>84.7</td>
<td>84.7</td>
</tr>
<tr>
<td>pH24h</td>
<td>978, 1,190, 1,348, 1,450, 1,784, 1,920nm</td>
<td>72.2</td>
<td>83.3</td>
<td>77.8</td>
<td>88.9</td>
<td>84.7</td>
<td>84.7</td>
</tr>
<tr>
<td>DL2d</td>
<td>978, 1,190, 1,348, 1,450, 1,784, 1,920nm</td>
<td>78.4</td>
<td>74.3</td>
<td>76.4</td>
<td>88.9</td>
<td>84.7</td>
<td>84.7</td>
</tr>
<tr>
<td>DL7d</td>
<td>950, 1,140, 1,386, 1,756, 1,872††</td>
<td>72.2</td>
<td>80.6</td>
<td>76.4</td>
<td>88.9</td>
<td>84.7</td>
<td>84.7</td>
</tr>
<tr>
<td>WU6h</td>
<td>950, 1,140, 1,386, 1,756, 1,872††</td>
<td>61.3</td>
<td>82.9</td>
<td>73.6</td>
<td>80.6</td>
<td>86.1</td>
<td>86.1</td>
</tr>
<tr>
<td>WU24h</td>
<td>978, 1,190, 1,348, 1,450, 1,784, 1,920nm</td>
<td>67.6</td>
<td>84.2</td>
<td>76.4</td>
<td>79.4</td>
<td>92.1</td>
<td>86.1</td>
</tr>
</tbody>
</table>

1WHC = water-holding capacity. L* = lightness. pH2h = pH at 2 h; pH24h = pH at 24 h. DL2d = drip loss % at 2 d; DL7d = drip loss % at 7 d. WU6h = salt-induced water uptake % at 6 h; WU24h = salt-induced water uptake % at 24 h.

2High-WHC fillet criteria: L* < 54.0, pH2h > 6.07, pH24h > 6.00, DL2d < 0.75%, DL7d < 2.95%, WU6h > 30%, WU24h > 40%.

3Low-WHC fillet criteria: L* > 54.0, pH2h < 6.07, pH24h < 6.00, DL2d > 0.75%, DL7d > 2.95%, WU6h < 30%, WU24h < 40%.

†Unprocessed spectra data.

††Second derivative of spectra data.
REFERENCES


