Use of visible and near-infrared spectroscopy to predict pork longissimus lean color stability[1,2,3]

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ABSTRACT: This study evaluated the use of visible and near-infrared (VISNIR) spectroscopy to predict lean color stability in pork loin chops. Spectra were collected immediately after and approximately 1 h after rib removal on 1,208 loins. Loins were aged for 14 d before a 2.54-cm chop was placed in simulated retail display. Spectra were collected on aged loins immediately after removal from the vacuum package and on chops 10 min after cutting. Instrumental color measurements [L*, a*, b*, hue angle, chroma, and ΔE (overall color change)] were determined on d 0, 1, 7, 11, and 14 of display. Principal components analysis of display d 0 and 14 values of these traits identified a factor (first principal component; PC1) explaining 67% of the variance that was related to color change. Partial least squares regression was used to develop 3 models to predict PC1 values by using VISNIR spectra collected in the plant, on aged loins, and on chops. Loins with predicted PC1 values less than 0 were classified as having a stable color, whereas values greater than 0 were classified as having a labile lean color. Loins classified as stable by the in-plant model had smaller ($P < 0.05$) L* values than those classified as labile. Hue angle and ΔE values were less ($P < 0.05$) and a* and chroma values were greater ($P < 0.05$) after d 7 of display in loins predicted to have a stable color than in loins predicted to have a labile lean color. Similarly, chops from loins classified as stable using the aged loin model had smaller ($P < 0.05$) L* values than those from loins classified as labile. Furthermore, loins predicted to be stable had smaller ($P < 0.05$) hue angle and ΔE values and greater ($P < 0.05$) a* and chroma values after d 7 of display than did loins predicted to be labile. Results for the chop model were similar to those from the 2 loin models. Chops predicted to have a stable lean color had smaller ($P < 0.05$) L* values than did those predicted to have a labile lean color. Chops classified as stable had smaller ($P < 0.05$) hue angle and ΔE values and greater ($P < 0.05$) a* and chroma values after d 7 of display compared with chops classified as labile. All 3 models effectively segregated chops based on color stability, particularly with regard to redness. Regardless of the model being used, d 14 display values for a*, hue angle, and ΔE in loins classified as stable were similar to the d 7 values of loins classified as labile. Thus, these results suggest that VISNIR spectroscopy would be an effective technology for sorting pork loins with regard to lean color stability.

Key words: color stability, pork, prediction, visible and near-infrared spectroscopy

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INTRODUCTION

Lean color is a primary factor influencing consumer purchase decisions of meat products (Kropf, 1980). Discounting or discarding packages containing chops that have prematurely discolored is a substantial cost to the industry. This is particularly true when a discolored chop is packaged with other chops possessing adequate color life in a "family-sized" package (Holmer and Sutton, 2009).

The lean color and color stability of pork are greatly influenced by antemortem factors, such as genetics (Newcom et al., 2004; Lindahl et al., 2006b) and stress (Rosenvold and Andersen, 2003; Lindahl et al., 2006a). These factors influence the metabolic status of the muscle at death, consequently affecting the rate of pH and

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temperature decline early postmortem. Early postmortem pH and temperature interact to affect lean color and the activity of reductive enzyme systems needed to maintain lean color during display (Offer, 1991; Lindahl et al., 2006a). Because these factors vary widely in the pigs slaughtered at commercial facilities, ensuring a satisfactory color life of loins destined for branded products is difficult.

Technology that would allow pork loins with insufficient color life to be identified and excluded from retail product lines would largely mitigate this problem. Visible and near-infrared (**VISNIR**) spectroscopy has shown promise in predicting numerous pork quality attributes (Brøndum et al., 2000; Forrest et al., 2000; Geesink et al., 2003; Savenije et al., 2006). Noninvasive VISNIR technology capable of operating at commercial line speeds has been developed for predicting beef tenderness (Shackelford et al., 2005; Price et al., 2008), and this technology has been expanded for use in predicting pork LM tenderness (Shackelford et al., 2011). The present experiment was designed to develop models using VISNIR spectra collected on pork loins immediately after fabrication, on aged pork loins, or on aged loin chops to predict retail color life.

MATERIALS AND METHODS

Animal care and use approval was not obtained for this study because the samples were obtained from federally inspected slaughter facilities.

Sample Collection

Boneless, center-cut pork loins (n = 1,208) were selected from the boning lines of 4 large-scale processing facilities at approximately 24 h postmortem. Loins were cut similar to Institutional Meat Purchase Specification #412B (NAMP, 2003) with the modification that all accessory muscles except the gluteus medius were removed. All 4 plants used CO_2 stunning. Two of the plants sampled for this study chilled carcasses using conventional chilling, whereas the other 2 used blast chilling. At each plant, 300 loins were selected in 2 separate groups on a single production day so that the sampled loins represented multiple production lots. Vacuum-packaged loins were transported to the US Meat Animal Research Center meat laboratory and stored at 1°C until 14 d postmortem. A 2.54-cm-thick chop was cut from the 10th-rib region of each loin and placed in simulated retail display.

Simulated Retail Display

Chops were placed on polystyrene trays with soaker pads and overwrapped with oxygen-permeable polyvinylchloride film [Crystal Clear PVC Wrapping Film, Koch Supplies, Kansas City, MO; oxygen transmission rate = 15,500 to 16,275 cm^3 of $O_2/(m^2/24\ h)$ at 23°C]. Chops were placed under continuous fluorescent lighting (color temperature = 3,500 K; color rendering index = 86; 32 W; T8 Ecolux bulb, model number F32T8/SPX35 GE, GE Lighting, Cleveland, OH) for 14 d. Light intensity at the meat surface measured approximately 2,000 lx. Display was conducted in a refrigerated room (1°C), and no temperature fluctuations associated with defrost cycles were encountered.

Chops were allowed to bloom for at least 2 h before color measurement began. Instrumental color readings were taken on the LM on d 0, 1, 7, 11, and 14 of display using a Hunter Miniscan XE Plus colorimeter (HunterLab, Reston, VA) with a 25-mm port. The colorimeter was set to collect spectral data with Illuminant A and a 10° observer. The CIE L* (lightness), a* (redness), and b* (yellowness) color-space values were reported as the average of duplicate readings taken on each chop. Greater L*, a*, and b* values are indicative of increased lightness, redness, and yellowness, respectively. Chroma (color intensity, also known as the saturation index) was calculated as $[(a^{*2} + b^{*2})^{0.5}]$. Hue angle was calculated as [arctangent (b*/a*)*180/3.142]. The overall color change (**ΔE**) was calculated as $[(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{0.5}]$, where ΔL*, Δa*, and Δb* are the difference between d 0 and d 1, 7, 11, or 14 values of L*, a*, and b*, respectively.

Collection of VISNIR Spectra

Visible and near-infrared spectra (350 to 1050 nm) were collected according to protocols described by Shackelford et al. (2004) on the ventral surface of the LM exposed by removal of the back ribs. To facilitate development of robust prediction models, spectra were collected with 2 identical spectrophotometers (Model QSP 3505-1050V, Analytical Spectral Devices Inc., Boulder, CO), which have been described in detail by Shackelford, Wheeler, King, and Koohmaraie (US Meat Animal Research Center, Clay Center, NE; unpublished data). In the processing plant, spectral data were collected using both spectrophotometers immediately after back rib removal on the ventral side of the LM, and off-line approximately 1 h later in the same location. Spectra were collected on bloomed and unbloomed loins so that the resulting model would not be influenced by bloom time when applied in an industry setting. Because of equipment failure, only 1 spectrophotometer was used for on-line and off-line measurements in the first plant; however, this spectrophotometer was used in subsequent plants.

Spectral data also were collected on each loin immediately after removal from vacuum packaging on d 14 postmortem to simulate measurements that might be taken by purveyors implementing VISNIR sorting. These spectra were collected on the ventral surface of the longissimus thoracis in the same manner used for the in-plant spectra collection. Moreover, spectra were collected on the chop surface (cross-section of the LM

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muscle) 10 min after the chop had been cut to allow development of a model for use directly on pork loin chops.

Statistical Analysis

Color variables collected on d 0 and 14 of display were used to develop a 4-principal component model to highlight relationships in these color variables by using Unscrambler X (Camo Software Inc., Woodbridge, NJ). The first 2 principal components explained 67 and 14% of the variance in these traits, respectively. Plotting the loadings for these variables for the first 2 principal components (Figure 1) indicated that the d 14 values of variables exhibiting the most change during display (i.e., a*, hue angle, and ΔE) made the greatest contributions to the first principal component (**PC1**). Thus, it was determined that PC1 was most closely associated with color change, whereas the second component (**PC2**) was more closely associated with initial color values. Preliminary testing indicated that sorting loins using VISNIR models developed to predict PC1 produced groups that were different with regard to the change in all color attributes, whereas sorting with VISNIR models developed to predict a single attribute did not uniformly affect all other color variables.

Data from the loins from a given plant were blocked with regard to the observed color change measured on d 14 of display and were assigned to calibration and prediction data sets. Thus, the calibration and prediction data sets had similar variance for color attributes and were balanced across potential plant differences. Partial least-squares regression was conducted using the Unscrambler X software. Models accounting for the covariance between PC1 and PC2 were developed to predict PC1 values using VISNIR spectra of the calibration data set, and models were validated on spectra from the prediction data set. Three separate models were developed to predict the PC1 values derived from simulated retail display data. These models were developed using the spectra collected in the plant (on-line and off-line combined), on the loin at 14 d postmortem, and on the chop at 14 d postmortem (after 10 min of oxygenation), respectively. The resulting models were used to predict the PC1 values of each loin by using the spectra from the spectrophotometer that was used in all the spectra collection sessions. Predicted PC1 values greater than 0 were classified as labile, whereas those less than 0 were classified as stable. This was an arbitrary threshold selected so that approximately one-half of the samples would be in each of the stable and labile classifications.

The effects of VISNIR sorting for color stability were ascertained separately for the calibration and prediction data sets by using the PROC MIXED procedure (SAS Inst. Inc., Cary, NC). Data were analyzed as a repeated measures design. The model included the fixed effects of stability classification and day of display and their interaction. Plant was included as a random effect. The repeated measures were modeled using an unstructured

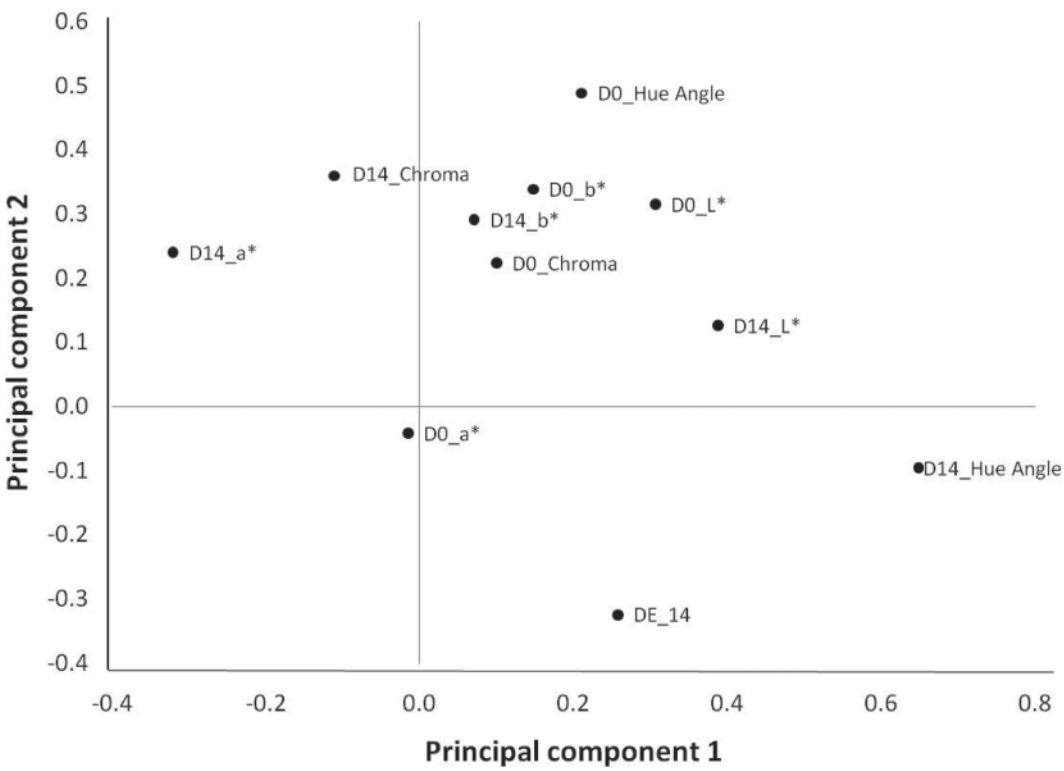

Figure 1. Principal components analysis of color variables of pork loins collected on d 0 (D0) and 14 (D14) of simulated retail display. L* = lightness; a* = redness; b* = yellowness; hue angle = [arctangent(b*/a*)*180/3.142]; chroma = $[(a^{*2} + b^{*2})^{0.5}]$. DE_14 = overall color change on d 14 of display.

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Table 1. Simple statistics for instrumental color traits of 1,208 pork chops from loins selected from 4 commercial processing facilities

Variable[1]	Mean	SD	Minimum	Maximum	CV
L*					
d 0	59.1	3.5	45.5	69.8	5.9
d 14	59.6	3.8	46.5	70.5	6.4
a*					
d 0	18.4	1.5	13.4	23.5	8.0
d 14	14.1	3.0	4.2	23.1	21.3
b*					
d 0	20.9	2.2	14.5	27.0	10.4
d 14	21.1	1.7	15.1	25.0	8.1
Hue angle					
d 0	44.8	3.1	34.0	54.2	6.8
d 14	52.0	5.8	38.4	73.4	11.2
Chroma					
d 0	27.9	2.1	21.2	34.4	7.4
d 14	25.5	2.1	19.1	31.6	8.0
ΔE					
d 14	5.0	2.9	0.2	17.6	56.7
PC1	0.1	8.7	−21.9	30.0	11,302.2
PC2	0.0	4.1	−15.2	9.3	−25,340.4
pH	5.6	0.2	5.2	6.5	37.5

[1]L* = lightness; a* = redness; b* = yellowness; hue angle = [arctangent(b*/a*)*180/3.142]; chroma = $[(a^{*2} + b^{*2})^{0.5}]$; ΔE (overall color change) = $[(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{0.5}]$; PC1 = first principal component; PC2 = second principal component.

covariance structure. Least squares means were generated for significant interactions and main effects not involved in significant interactions and were separated using the DIFF option with a Scheffé adjustment and a predetermined significance level of 0.05.

RESULTS

Simple statistics characterizing the initial and final color properties of the loins included in the present experiment are presented in Table 1. The loins selected for the present experiment represented considerable variation in initial color, as well as the extent of change in color variables during display. The greatest variability in color traits, as evidenced by CV values, was detected in the overall color change (ΔE) and hue angle values on d 14, which appeared to be largely driven by a* values on d 14.

Principal components analysis was conducted on the color variables measured on d 0 and 14 of display as a method of condensing the color variables into a single variable for use in regression analyses. The first 2 principal components accounted for 67 and 14% of the variation in initial and final color variables, respectively. The PC1 was most closely related to color variables determined on d 14 of display, particularly d 14 hue angle, L*, ΔE, and a* values (Figure 1). The strong contribution of d 14 hue angle to the principal component accounting for the greatest portion of the variance in this data set, further emphasizes that the redness was the most variable attribute at the end of display in these loin chops. The PC2 was most closely related to initial color, particularly L*, b*, and color intensity. Thus, visible and near-infrared spectra were used to develop models to predict PC1 values as an indicator of lean color stability.

In-Plant Model

The effects of using the in-plant model to sort pork loins were tested on predictions obtained from spectra collected on-line from 1 instrument. The accuracy of this prediction model is shown in Figure 2. Coefficients of determination of this model on the calibration and prediction data sets were 0.45 and 0.40, respectively. Loins were segregated into predicted stability classes based on the predicted PC1 value. Loins with predicted PC1 values less than 0 were classified as stable, whereas those with predicted PC1 values greater than 0 were classified as labile. The frequency distribution of actual PC1 values of the loins in each of the predicted stability groups in the calibration data set indicate that the model was able to sort loins into categories effectively. Of the loins classified as stable, only 9.6% had observed PC1 values greater than 5, whereas 47.8% of the loins classified as labile had observed PC1 values greater than 5. This also was evident in the frequency distribution of PC1 values from the prediction data set, in which the stable and labile classifications had 9.4 and 47.5% of the loins with observed PC1 values greater than 5.

Predicted stability class interacted with day of display to affect all traits except L* in both the calibration and prediction data sets (Table 2). In the calibration data set, loin chops classified as stable had lesser ($P < 0.05$) L* values than those predicted to be labile. In both stability classes, L* was greater ($P < 0.05$) on d 0 and 14 of display than on d 1, 7, or 11 of display.

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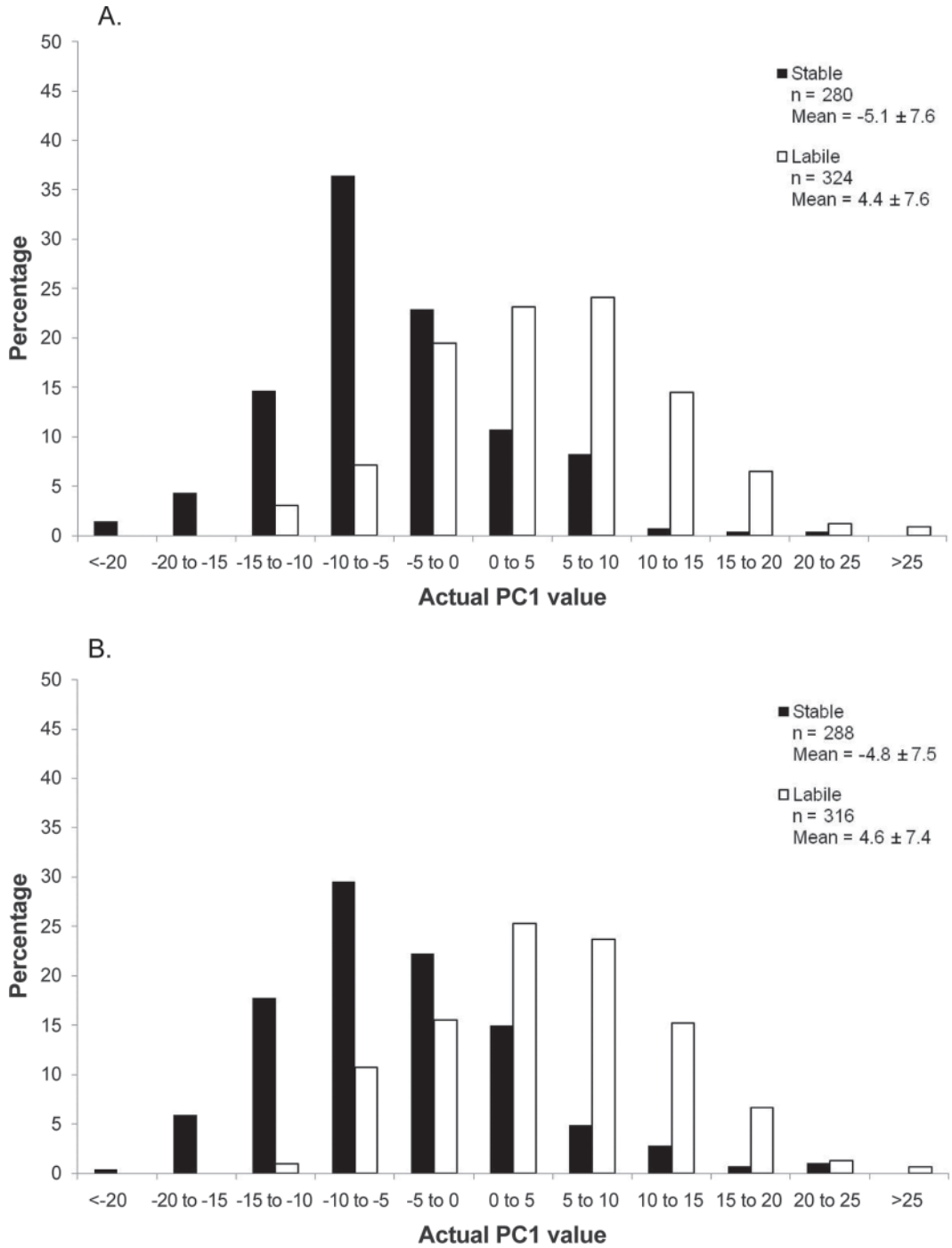

Figure 2. Frequency distributions of actual first principal component (PC1) values for pork loins in the calibration (panel A) and prediction (panel B) data sets classified into lean color stability categories using a visible and near-infrared (VISNIR) spectroscopy model developed on the rib side of loins immediately after fabrication. The stable class included loins with predicted PC1 values less than 0. The labile class included loins with predicted PC1 values greater than 0.

However, these differences across display time were relatively small.

Redness (a* values) decreased in loin chops from both stability classes as display progressed from d 1 to 14 (Table 2). However, the decline in redness was much more extensive in loin chops predicted to be labile than in those predicted to be stable. In the calibration data set, redness increased ($P < 0.05$) slightly between d 0 and 1 in loin chops predicted to be stable and then decreased ($P < 0.05$) between d 1 and 7 and again between d 11 and 14. Redness did not differ between d 0 and 1 in loin chops classified as labile, but then it decreased ($P < 0.05$) progressively throughout the remaining display period. Mean a* values for loin chops predicted to be stable on d 14 of display were similar to those of loin chops predicted to be labile on d 7. Yellowness (b*) values were greater ($P < 0.05$) in loin chops predicted to be labile than in those predicted to be stable on d 0 and 1, but b* values did not differ across stability classifications on d 7 or beyond.

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Table 2. Least squares means for color traits of pork LM chops in the calibration and prediction data sets classified as stable or labile by using visible and near-infrared spectroscopy models developed on spectra collected immediately after processing

	Day of display						*P*-value		
Item[1]	0	1	7	11	14	SEM	Stability class	Day	Stability class × day
Calibration data set									
L*									
Stable	57.2	56.9	56.6	56.4	57.4	0.5	<0.001	<0.001	0.30
Labile	60.8	60.4	60.0	60.3	61.4				
a*									
Stable	18.4[b]	18.9[a]	17.5[c]	16.8[c]	15.7[de]	0.2	<0.001	<0.001	<0.001
Labile	18.4[b]	18.6[ab]	15.8[d]	14.4[e]	12.8[f]				
b*									
Stable	20.1[e]	20.9[cd]	21.0[cd]	21.1[bcd]	20.9[d]	0.4	<0.001	<0.001	<0.001
Labile	21.6[ab]	22.0[a]	21.4[bc]	21.2[bcd]	21.3[d]				
Hue angle									
Stable	43.8[g]	44.1[g]	46.4[f]	47.5[de]	49.0[cd]	0.6	<0.001	<0.001	<0.001
Labile	45.6[f]	45.8[f]	49.3[c]	51.4[b]	54.4[a]				
Chroma									
Stable	27.3[d]	28.3[b]	27.4[c]	27.0[e]	26.2[f]	0.4	<0.001	<0.001	<0.001
Labile	28.4[a]	28.9[a]	26.7[f]	25.8[g]	25.0[h]				
ΔE									
Stable		1.7[e]	2.6[d]	3.2[cd]	3.7[c]	0.2	<0.001	<0.001	<0.001
Labile		1.6[e]	3.3[c]	4.7[b]	6.0[a]				
Prediction data set									
L*									
Stable	57.3	57.2	56.8	56.7	57.7	0.4	<0.001	<0.001	0.30
Labile	60.9	60.4	60.0	60.4	61.5				
a*									
Stable	18.3[a]	18.9[a]	17.4[b]	16.8[b]	15.6[c]	0.1	<0.001	<0.001	<0.001
Labile	18.4[a]	18.6[a]	15.8[c]	14.3[d]	12.7[e]				
b*									
Stable	20.1[e]	21.0[cd]	21.0[cd]	21.0[cd]	20.9[d]	0.4	<0.001	<0.001	<0.001
Labile	21.7[ab]	22.2[a]	21.4[bc]	21.2[bcd]	21.2[bcd]				
Hue angle									
Stable	43.9[f]	44.2[f]	46.4[e]	47.4[d]	49.2[c]	0.6	<0.001	<0.001	<0.001
Labile	45.6[e]	45.9[e]	49.4[c]	51.5[b]	54.6[a]				
Chroma									
Stable	27.3[d]	28.2[b]	27.3[c]	27.0[e]	26.2[f]	0.4	<0.001	<0.001	<0.001
Labile	28.5[a]	29.0[a]	26.7[f]	25.7[g]	24.9[h]				
ΔE									
Stable		1.7[f]	2.6[e]	3.2[d]	3.8[c]	0.2	<0.001	<0.001	<0.001
Labile		1.6[f]	3.4[cd]	4.8[b]	6.2[a]				

[a–h]Least squares means, within a trait, lacking common superscripts differ ($P < 0.05$).

[1]L* = lightness; a* = redness; b* = yellowness; hue angle = [arctangent(b*/a*)*180/3.142]; chroma = $[(a^{*2} + b^{*2})^{0.5}]$; ΔE (overall color change) = $[(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{0.5}]$. The stable class included loins with predicted first principal component (PC1) values less than 0. The labile class included loins with predicted PC1 values greater than 0.

Hue angle values indicated that loin chops predicted to have a stable lean color had a more red hue at all display times. Although the red hue decreased (increased hue angle values; $P < 0.05$) during display in both stability classes, the loss of redness was less extensive in chops from loins predicted to be stable than in those from loins predicted to be labile. In fact, hue angle values of loin chops predicted to be labile on d 0 of display were similar to the hue angle values of loin chops predicted to be stable on d 7. Initially (d 0 and 1), color intensity (chroma) values were greater in loin chops predicted to be labile than in those predicted to be stable. However, by d 7, color intensity values of loin chops predicted to be labile had declined ($P < 0.05$) to a point that was less ($P < 0.05$) than the values of chops predicted to be color stable. All these differences in color traits are reflected in overall color change (ΔE) values. Color change was similar between predicted color stability classifications on d 1 of display. On d 7, 11, and 14, color change was greater ($P < 0.05$) in loin chops predicted to be labile than in those predicted to be stable. Color change increased ($P < 0.05$) slightly between d 7 and 11 in chops predicted to be stable. However, color change increased ($P < 0.05$) to a greater degree in chops predicted to be labile between d 7 and 11 and again between d 11 and 14 so that the differences between color stability classifications became progressively larger. The differences in color variables

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and trends in changes in these variables associated with sorting loins based on predicted PC1 values in the prediction data set (Table 2) are remarkably consistent with those discussed above for the same comparisons in the calibration data set. Thus, it appears that using the on-line VISNIR prediction model to sort pork loins into product lines based on lean color stability would be highly effective.

Aged Loin Model

Preliminary analyses indicated that spectra collected in the processing plant on d 1 postmortem differed substantially from those collected on d 14 on the aged loin. Because some purveyors may desire to sort aged loins into color stability groups, a second model was developed using spectra collected on the ventral aspect of the boneless loins on d 14 postmortem immediately after they were removed from the vacuum package, to predict the PC1 values derived from the simulated retail display data. The accuracy of this 14-factor model in segregating the loins in the calibration and prediction data sets into PC1 categories is shown in Figure 3. Coefficients of determination of this model were 0.50 and 0.49 in the calibration and prediction data sets, respectively. In the calibration data set, only 6% of the loins classified as stable produced chops with PC1 values greater than 5, whereas 53.3% of the chops from loins classified as labile produced chops with PC1 values greater than 5. In the prediction data set, 7.4 and 50.8% of the chops from loins classified as stable and labile, respectively, had PC1 values greater than 5. The effects of sorting loins using this model on instrumental color attributes are presented in Table 3. The predicted color stability classification interacted with day of display to affect ($P < 0.05$) all the color variables evaluated in this experiment except L* values in both the calibration and prediction data sets. In the calibration data set, loins classified as labile had a lighter lean color (greater L* values; $P < 0.05$) than those predicted to have a stable lean color regardless of the day of display. The L* values differed ($P < 0.05$) across days of display in the loins of both predicted color stability classifications, but these differences were small and not likely of practical importance.

Redness (a* values) did not differ between predicted color stability classes on d 0 or 1 of display, but d 14 a* values of loins predicted to be stable were greater ($P < 0.05$) than the a* values of loins predicted to be labile on d 7, 11, and 14 of display. The yellowness (b* values) of loins classified as labile on d 0 and 1 of display was greater than ($P < 0.05$) the that of loins classified as stable. However, by d 7 of display, no difference in b* values was detected between color stability classifications. Trends associated with hue angle largely agreed with those associated with a* values in that chops from loins predicted to have a labile lean color had a redness (hue angle values) similar to that of loin chops predicted to have a stable lean color on d 1 of display, but had less ($P < 0.05$) redness on d 7 through 14 of display compared with loin chops predicted to have a stable lean color. It is notable that chops from loins predicted to have a stable lean color had hue angle values on d 14 of display similar to those measured on chops from loins predicted to be labile on d 7 of display. Color intensity was greater ($P < 0.05$) on d 0 of display in chops from loins predicted to have a labile lean color compared with those predicted to have a stable lean color. However, on d 7 through 14 of display, chops from loins classified as having a labile lean color had smaller ($P < 0.05$) chroma values than those classified as having a stable lean color. In fact, the chroma values of chops from the stable group on d 14 of display were similar to those of the labile group on d 7 of display. The overall color change (ΔE) was much less extensive in chops from loins predicted to have a stable lean color than in those from loins predicted to be labile. On d 1, ΔE values did not differ between stability classifications, but by d 7 of display, the color change in chops from loins predicted to be stable was similar to the color change detected in loins predicted to be stable by d 14 of display. The differences between color stability classifications using the 14 d postmortem loin model detected in the prediction data set were remarkably similar to those discussed above for the calibration data set. Overall, the outcomes associated with sorting the loins in this study with the aged loin model were very similar to those associated with sorting the same loins using the in-plant model.

Chop Model

In some cases, VISNIR predictions might be useful in evaluating packages of loins that are already designated for a product line. Thus, spectra were collected on chops cut from the aged (14-d) loins. Figure 4 illustrates that this model also was effective in segregating loins into groups based on the predicted PC1 values. Coefficients of determination for this model were 0.49 in both the calibration and prediction data sets. Of the chops classified as stable in the calibration data set, 7.2% had PC1 values greater than 5, whereas 50.6% of those classified as labile had PC1 values greater than 5. In the prediction data set, the stable and labile categories had 6.3 and 48.1% of the chops with PC1 values greater than 5, respectively. The effects of sorting loin chops using this model on instrumental color attributes during display are shown in Table 4. As noted for the other 2 models, a stability class × day of display interaction was detected for all attributes except L*. In the calibration data set, L* values indicated that chops classified as stable had a darker ($P < 0.05$) lean color than those that were predicted to be labile. Loin chops predicted to have a labile color had much smaller ($P < 0.05$) a* values on d 7, 11, and 14 of display than those predicted to have a stable lean color. The differences

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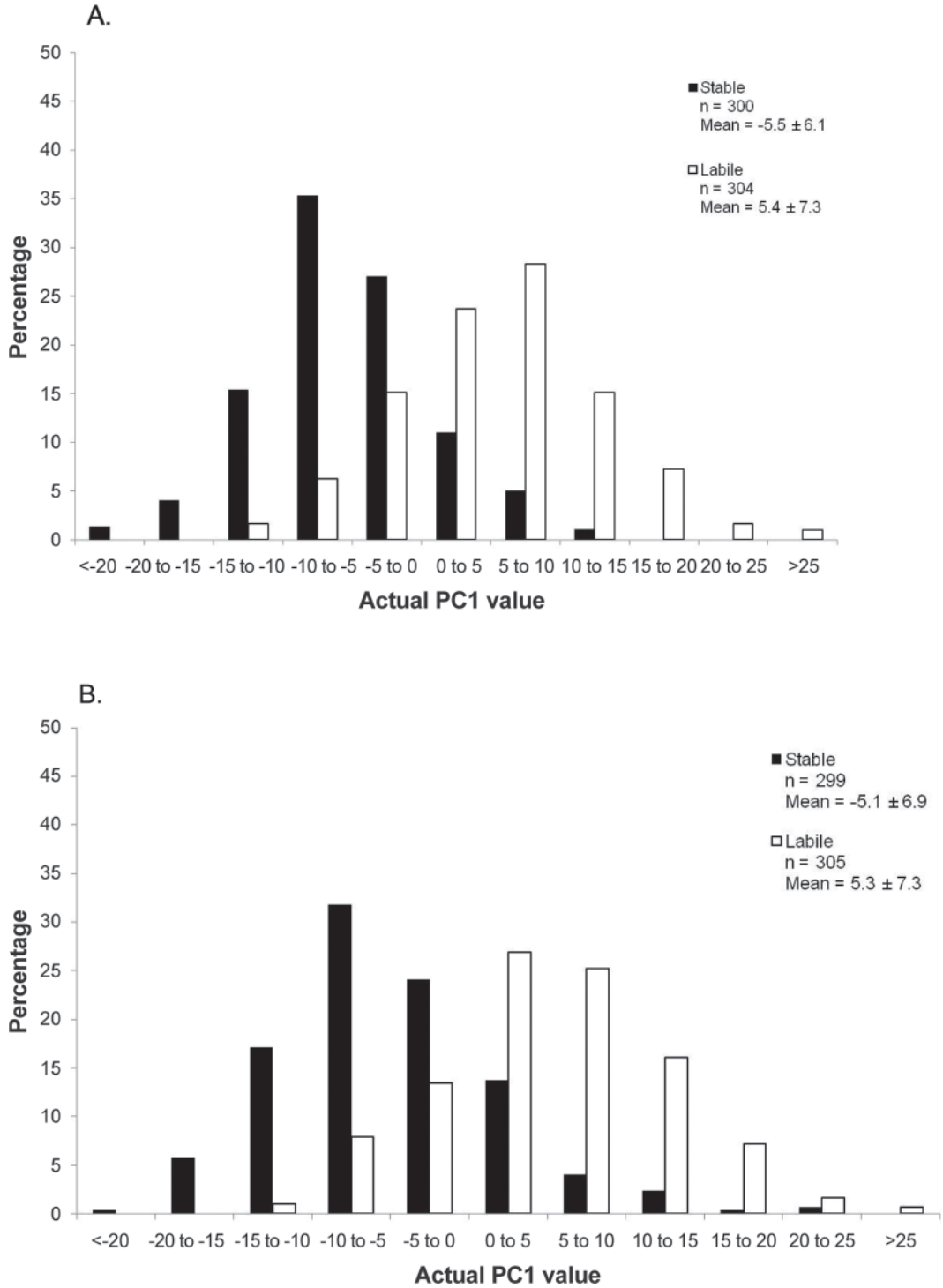

Figure 3. Frequency distributions of actual first principal component (PC1) values for pork loins in the calibration (panel A) and prediction (panel B) data sets classified into lean color stability categories using a visible and near-infrared spectroscopy model developed on the rib side of loins on d 14 postmortem. The stable class included loins with predicted PC1 values less than 0. The labile class included loins with predicted PC1 values greater than 0.

in a* values detected between color stability classes increased in magnitude as the display period progressed. Yellowness (b*) values were greater ($P < 0.05$) in chops classified as labile on d 0 and 1 of display than in those classified as stable, but no difference was detected in b* values between stability groups on d 7, 11, or 14 of display. Hue angle values indicated that chops classified as labile had a less red hue throughout the display period. The magnitude of this difference became larger as the display period progressed so that the hue angles of chops classified as stable on d 14 of display were similar to those of chops classified as labile on d 7 of display. Chroma was greater ($P < 0.05$) in chops classified as labile on d 0 of display compared with chops classified as stable; however, the chroma values of labile chops were less ($P < 0.05$) than the chroma values of stable chops

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Table 3. Least squares means for color traits of pork LM chops in the calibration and prediction data sets classified as stable or labile using visible and near-infrared spectroscopy models developed on spectra collected on loins at 14 d postmortem

	Day of display						*P*-value		
Item[1]	0	1	7	11	14	SEM	Stability class	Day	Stability class × day
Calibration data set									
L*									
Stable	57.0	56.7	56.5	56.3	57.3	0.4	<0.001	<0.001	0.20
Labile	61.1	60.7	60.3	60.6	61.8				
a*									
Stable	18.3[b]	18.9[a]	17.6[c]	17.0[c]	15.9[d]	0.2	<0.001	<0.001	<0.001
Labile	18.5[ab]	18.6[ab]	15.6[e]	14.1[f]	12.4[g]				
b*									
Stable	20.2[d]	21.0[c]	21.2[bc]	21.3[bc]	21.1[bc]	0.4	<0.001	<0.001	<0.001
Labile	21.6[ab]	22.0[a]	21.3[bc]	21.0[c]	21.1[c]				
Hue angle									
Stable	44.0[g]	44.2[g]	46.4[ef]	47.4[de]	48.8[cd]	0.6	<0.001	<0.001	<0.001
Labile	45.5[f]	45.8[f]	49.4[c]	51.7[b]	54.9[a]				
Chroma									
Stable	27.3[b]	28.3[a]	27.6[b]	27.3[b]	26.5[c]	0.4	<0.001	<0.001	<0.001
Labile	28.5[a]	28.9[a]	26.4[c]	25.4[d]	24.6[e]				
ΔE									
Stable		1.7[f]	2.4[e]	3.0[d]	3.4[cd]	0.2	<0.001	<0.001	<0.001
Labile		1.6[f]	3.5[c]	5.0[b]	6.5[a]				
Prediction data set									
L*									
Stable	57.0	56.8	56.6	56.4	57.4	0.3	<0.001	<0.001	0.10
Labile	61.3	60.9	60.3	60.8	62.0				
a*									
Stable	18.2[b]	18.9[a]	17.4[c]	16.9[c]	15.7[d]	0.1	<0.001	<0.001	<0.001
Labile	18.6[ab]	18.6[ab]	15.7[d]	14.1[e]	12.4[f]				
b*									
Stable	20.2[d]	21.0[c]	21.3[bc]	21.4[bc]	21.1[c]	0.4	<0.001	<0.001	<0.001
Labile	21.7[ab]	22.2[a]	21.2[bc]	20.9[c]	21.0[c]				
Hue angle									
Stable	44.1[g]	44.3[g]	46.7[de]	47.7[cd]	49.3[c]		<0.001	<0.001	<0.001
Labile	45.5[f]	45.9[ef]	49.2[c]	51.5[b]	54.8[a]	0.6			
Chroma									
Stable	27.2[c]	28.3[b]	27.6[c]	27.3[c]	26.4[d]	0.4	<0.001	<0.001	<0.001
Labile	28.6[ab]	29.0[a]	26.4[d]	25.3[e]	24.5[f]				
ΔE									
Stable		1.7[f]	2.4[e]	3.1[d]	3.6[c]	0.2	<0.001	<0.001	<0.001
Labile		1.6[g]	3.6[c]	5.0[b]	6.6[a]				

[a–g]Least squares means, within a trait, lacking common superscripts differ ($P < 0.05$).

[1]L* = lightness; a* = redness; b* = yellowness; hue angle = [arctangent(b*/a*)*180/3.142]; chroma = $[(a^{*2} + b^{*2})^{0.5}]$; ΔE (overall color change) = $[(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{0.5}]$. The stable class included loins with predicted first principal component (PC1) values less than 0. The labile class included loins with predicted PC1 values greater than 0.

on d 7, 11, or 14 of display. On d 1 of display, ΔE values did not differ between stability classifications, but by d 1, chops classified as stable exhibited less ($P < 0.05$) color change. The difference in color change between color stability classifications became larger as display progressed. The differences associated with sorting the prediction data set with the chop model were remarkably consistent with the differences discussed above for the calibration data set. Furthermore, the differences associated with sorting the chops in the present study using the chop model were consistent with those associated with sorting loins using either the in-plant loin model or the aged loin model.

DISCUSSION

Visible and near-infrared spectroscopy has been evaluated for predicting several pork quality attributes, including lean color. Savenije et al. (2006) reported coefficients of determination raging from 0.70 to 0.89 for L* values, 0.66 to 0.72 for a* values, and 0.67 to 0.84 for b* values. However, to our knowledge, no previous reports are available evaluating VISNIR in predicting lean color stability during simulated retail display.

As branded product lines marketed in case-ready packaging have become more common, retailers have demanded greater shelf lives from fresh meat products.

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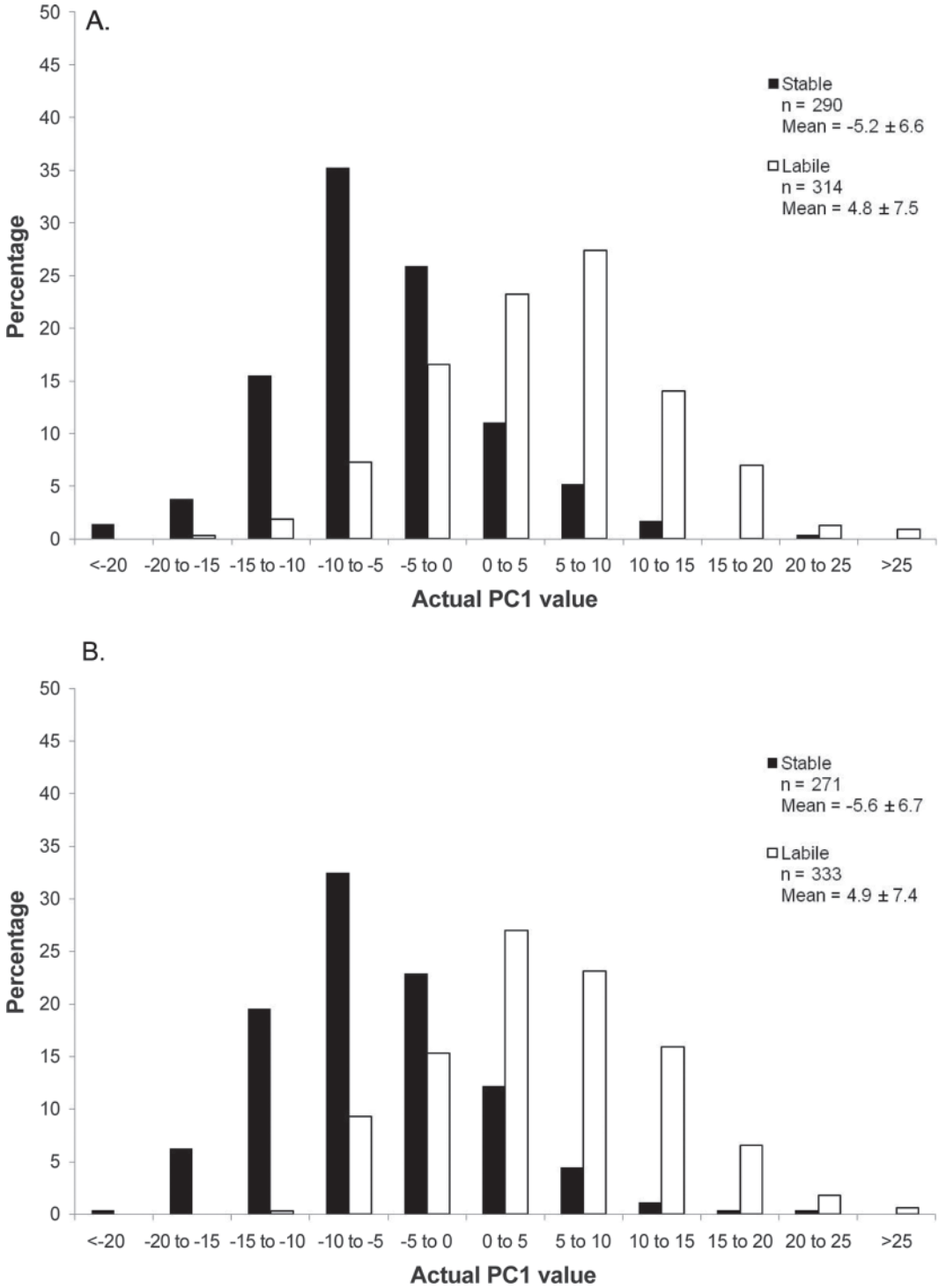

Figure 4. Frequency distributions of actual first principal component (PC1) values for pork loins in the calibration (panel A) and prediction (panel B) data sets classified into lean color stability categories using a visible and near-infrared spectroscopy model developed on loin chops on d 14 postmortem. The stable class included loins with predicted PC1 values less than 0. The labile class included loins with predicted PC1 values greater than 0.

Premature discoloration is even more problematic in pork loin chops that are often marketed in large "family-sized" packages containing chops from several loins. A single discolored chop in such a package results in the entire package being discounted or discarded, resulting in significant losses to the industry. Thus, it seems the most likely application of sorting loins with regard to color stability would be immediately postfabrication on the loin boning line. Loins predicted to have a stable lean color could be sent to chop cutting and packaging, whereas those predicted to have a labile lean color could be used for food service or in an enhanced or marinated product line, or could be marketed as whole vacuum-packaged loins. Furthermore, this technology might be used to exclude loins with an inadequate color life from shipments to export markets. Furthermore, the ability

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Table 4. Least squares means for color traits of pork LM chops in the calibration and prediction data sets classified as stable or labile using visible and near-infrared spectroscopy model developed on spectra collected on chops at 14 d postmortem

	Day of display						*P*-value		
Item[1]	0	1	7	11	14	SEM	Stability class	Day	Stability class × day
Calibration data set									
L*									
Stable	57.2	56.8	56.6	56.5	57.4	0.5	<0.001	<0.001	0.30
Labile	60.9	60.5	60.1	60.4	61.6				
a*									
Stable	18.2[b]	18.8[a]	17.5[c]	17.0[c]	15.9[d]	0.1	<0.001	<0.001	<0.001
Labile	18.6[ab]	18.7[a]	15.7[d]	14.2[e]	12.5[f]				
b*									
Stable	20.3[c]	21.1[b]	21.3[b]	21.4[ab]	21.2[b]	0.4	<0.001	<0.001	<0.001
Labile	21.5[ab]	21.9[a]	21.2[b]	20.9[b]	21.0[b]				
Hue angle									
Stable	44.3[i]	44.4[i]	46.6[ef]	47.6[de]	49.0[ed]	0.7	<0.001	<0.001	<0.001
Labile	45.2[gh]	45.5[fg]	49.2[c]	51.4[b]	54.5[a]				
Chroma									
Stable	27.3[b]	28.3[a]	27.6[b]	27.4[b]	26.6[c]	0.4	<0.001	<0.001	<0.001
Labile	28.4[a]	28.9[a]	26.4[c]	25.4[d]	24.6[e]				
ΔE									
Stable		1.7[e]	2.4[d]	3.0[c]	3.4[c]	0.2	<0.001	<0.001	<0.001
Labile		1.6[e]	3.5[c]	4.9[b]	6.4[a]				
Prediction data set									
L*									
Stable	57.0	56.8	56.5	56.4	57.3	0.4	<0.001	<0.001	0.30
Labile	61.0	60.6	60.1	60.5	61.7				
a*									
Stable	18.2[b]	18.8[a]	17.6[c]	17.1[c]	16.0[d]	0.1	<0.001	<0.001	<0.001
Labile	18.6[ab]	18.7[a]	15.7[d]	14.2[e]	12.5[f]				
b*									
Stable	20.1[d]	21.0[a]	21.2[bc]	21.3[bc]	21.1[c]	0.4	<0.001	<0.001	<0.001
Labile	21.7[ab]	22.1[a]	21.3[bc]	21.0[c]	21.1[c]				
Hue angle									
Stable	44.0[g]	44.3[g]	46.4[ef]	47.3[de]	48.8[cd]	0.6	<0.001	<0.001	<0.001
Labile	45.4[f]	45.8[f]	49.2[c]	51.5[b]	54.7[a]				
Chroma									
Stable	27.1[c]	28.2[b]	27.5[c]	27.3[c]	26.5[d]	0.3	<0.001	<0.001	<0.001
Labile	28.6[ab]	29.0[a]	26.5[d]	25.5[e]	24.6[f]				
ΔE									
Stable		1.8[f]	2.4[e]	2.9[de]	3.4[cd]	0.2	<0.001	<0.001	<0.001
Labile		1.6[f]	3.5[c]	5.0[b]	6.5[a]				

[a–i]Least squares means, within a trait, lacking common superscripts differ ($P < 0.05$).

[1]L* = lightness; a* = redness; b* = yellowness; hue angle = [arctangent(b*/a*)*180/3.142]; chroma = $[(a^{*2} + b^{*2})^{0.5}]$; ΔE (overall color change) = $[(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{0.5}]$. The stable class included loins with predicted first principal component (PC1) values less than 0. The labile class included loins with predicted PC1 values greater than 0.

to sort aged loins and chops also may be beneficial. The predictions were slightly different between the 3 models developed in the present experiment. However, sorting the loins with the 3 models produced results that were remarkably similar. Furthermore, the extremely high degree of agreement between the results in the calibration and prediction data sets underscores the effectiveness and robustness of these models.

In the present experiment, the threshold for designating loins as having stable or labile lean color was set at 0. This was an arbitrary value that roughly split the data in half. In commercial practice, this threshold would need to be optimized so that loins qualifying for a case-ready program would be ensured to have an adequate color life while not unnecessarily limiting the supply of qualified loins. This would largely depend on the pigs being sourced for the program, the color life required, the temperatures maintained during distribution and storage, and the expectations of the customer.

The greatest variability observed in the loin chops evaluated in this study was associated with redness at the end of display. Thus, regardless of the model, the greatest differences between chops from loins classified as stable and those from loins classified as labile were detected in a* and hue angle values. It should be noted that the present study was conducted under lower temperatures (1°C) than are typically used in retail display and that no temperature fluctuations attributable to

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defrost cycles were encountered. Thus, the rate of color change was likely slower than would be expected in commercial practice. However, after 7 d under the experimental conditions, the redness, and consequently overall color, of chops from loins classified as labile had deteriorated to a point that was not reached by chops from loins classified as stable until the end of the 14-d display period. Thus, under the experimental conditions, loins classified as having a stable lean color had a 7-d longer color life than those predicted to have a labile lean color. These results indicate that VISNIR spectroscopy could be effectively used to segregate pork loins into lean color stability categories in commercial application to minimize losses attributable to discarding or discounting pork products because of insufficient color stability.

LITERATURE CITED

Brøndum, J., L. Munck, P. Henckel, A. Karlsson, E. Tornberg, and S. B. Engelsen. 2000. Prediction of water-holding capacity and composition of porcine meat by comparative spectroscopy. Meat Sci. 55:177–185.

Forrest, J. C., M. T. Morgan, C. Borggaard, A. J. Rasmussen, B. L. Jespersen, and J. R. Andersen. 2000. Development of technology for the early post mortem prediction of water holding capacity and drip loss in fresh pork. Meat Sci. 55:115–122.

Geesink, G. H., F. H. Schreutelkamp, R. Frankhuizen, H. W. Vedder, N. M. Faber, R. W. Kranen, and M. A. Gerritzen. 2003. Prediction of pork quality attributes from near infrared reflectance spectra. Meat Sci. 65:661–668.

Holmer, S. F., and D. Sutton. 2009. Industry perspective on pork quality. Proc. Recip. Meat Conf. 62:1–3.

Kropf, D. H. 1980. Effects of retail display conditions on meat color. Proc. Recip. Meat Conf. 33:15–32.

Lindahl, G., P. Henckel, A. H. Karlsson, and H. J. Andersen. 2006a. Significance of early *postmortem* temperature and pH decline on colour characteristics of pork loin from different crossbreeds. Meat Sci. 72:613–623.

Lindahl, G., A. H. Karlsson, K. Lunström, and H. J. Andersen. 2006b. Significance of storage time on degree of blooming and colour stability of pork loin from different crossbreeds. Meat Sci. 72:603–612.

NAMP (National Association of Meat Purveyors). 2003. Meat Buyers Guide. Natl. Assoc. Meat Purveyors, Reston, VA.

Newcom, D. W., K. J. Stalder, T. J. Baas, R. N. Goodwin, F. C. Parrish, and B. R. Wiegand. 2004. Breed differences and genetic parameters of myoglobin concentration in porcine longissimus muscle. J. Anim. Sci. 82:2264–2268.

Offer, G. 1991. Modeling of the formation of pale, soft, and exudative meat: Effects of chilling regime and rate and extent of glycolysis. Meat Sci. 30:157–184.

Price, D. M., G. G. Hilton, D. L. VanOverbeke, and J. B. Morgan. 2008. Using the near-infrared system to sort various beef middle and end muscle cuts into tenderness categories. J. Anim. Sci. 86:413–418.

Rosenvold, K., and H. H. Andersen. 2003. The significance of preslaughter stress and diet on colour stability of pork. Meat Sci. 63:199–209.

Savenije, B., G. H. Geesink, J. G. P. van der Palen, and G. Hemke. 2006. Prediction of pork quality using visible/near-infrared reflectance spectroscopy. Meat Sci. 73:181–184.

Shackelford, S. D., D. A. King, and T. L. Wheeler. 2011. Development of a system for classification of pork loins for tenderness using visible and near-infrared reflectance spectroscopy. J. Anim. Sci. 89:3803–3808.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 2004. Development of optimal protocol for visible and near-infrared reflectance spectroscopic evaluation of meat quality. Meat Sci. 68:371–381.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 2005. Online classification of US Select beef carcasses for *longissimus* tenderness using visible and near-infrared reflectance spectroscopy. Meat Sci. 69:409–415.

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