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Field testing of a system for online classification of beef carcasses for longissimus tenderness using visible and near-infrared reflectance spectroscopy[1,2]

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ABSTRACT: The present experiments were conducted to field test a system optimized for online prediction of beef LM tenderness based on visible and near-infrared (VISNIR) spectroscopy and to develop and validate a model for prediction of tenderness that would be unbiased by normal variation in bloom time before application of VISNIR. For both Exp. 1 and 2, slice shear force (SSF) was measured on fresh (never frozen) steaks at 14 d postmortem. Carcasses with VISNIR-predicted SSF ≤15 kg were classified as VISNIR predicted tender and carcasses with VISNIR-predicted SSF >15 kg were classified as VISNIR not predicted tender. In Exp. 1, spectroscopy was conducted online, during carcass grading, at 3 large-scale commercial fed-beef processing facilities. Each carcass (n = 1,155) was evaluated immediately after ribbing and again when the carcass was graded. For model development and validation, carcasses were blocked by plant and observed SSF. One-half of the carcasses (n = 579) were assigned to a calibration data set, which was used to develop regression equations, and one-half of the carcasses (n = 576) were assigned to a prediction data set, which was used to validate the regression equations. Carcasses predicted tender by VISNIR spectroscopy had smaller ($P < 10^{-19}$) mean LM SSF values at 14 d postmortem in the calibration (13.9 vs. 16.5 kg) and prediction (13.8 vs. 16.4 kg) data sets than did carcasses not predicted tender by VISNIR spectroscopy. Relative to carcasses not predicted tender by VISNIR, a decreased percentage of carcasses predicted tender by VISNIR had LM SSF >25 kg in the calibration (2.0 vs. 7.8%) and prediction (0.8 vs. 8.0%) data sets. In Exp. 2, carcasses (n = 4,204) were evaluated with VISNIR online at 6 commercial fed-beef processing facilities on 38 production days. The carcasses predicted tender by VISNIR spectroscopy had decreased mean LM SSF values at 14 d postmortem (16.3 vs. 19.9 kg; $P < 10^{-87}$), longer sarcomere lengths (1.77 vs. 1.72 µm; $P < 10^{-10}$), and a greater percentage of desmin degraded (42 vs. 34%; $P < 10^{-5}$) by 14 d postmortem. Relative to carcasses not predicted tender by VISNIR, a decreased percentage of carcasses predicted tender by VISNIR had LM SSF >25 kg (4.9 vs. 21.3%). The present experiments resulted in development and independent validation of a robust method to noninvasively predict LM tenderness of grain-fed beef carcasses. This technology could facilitate tenderness-based beef merchandising systems.

Key words: beef, near-infrared, prediction, slice shear force, tenderness

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INTRODUCTION

A system for online classification of US Select beef carcasses for LM tenderness using visible and near-infrared (**VISNIR**) reflectance spectroscopy has been developed and validated (Shackelford et al., 2004, 2005, 2012). Although that system allowed for online tenderness prediction, it was not optimized for beef carcass

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Table 1. Number of sampling days, approximate number of hours postmortem at which carcasses were graded and evaluated by visible and near-infrared (VISNIR) spectroscopy, time elapsed from VISNIR evaluation at ribbing to VISNIR evaluation at grading stand, number of carcasses and lots sampled, and the distribution of carcasses by cattle type and quality grade[1]

				Time[4] (min:s)					Cattle type, No.			US Quality grade, No.			
Exp.	Plant	Sampling day[2]	Grading time,[3] h	Mean	Minimum	Maximum	Carcasses, No.	Lots, No.	Holstein steer	Beef steer	Beef heifer	Prime	Choice	Select	No roll
1	1	1–2	22–70	20:39	05:12	35:43	297	18	27	232	38	0	0	297	0
1	2	3–4	30–44	15:03	13:04	19:17	273	5	0	159	114	2	101	155	15
1	3	5	36	33:00	20:40	57:56	292	6	0	292	0	0	0	292	0
1	3	6	36	28:48	21:30	58:59	293	7	0	91	202	0	0	293	0
2	3	7–8	36	—[5]	—	—	351	18	0	280	71	0	0	351	0
2	4	9–11	48–72	—	—	—	602	26	4	480	118	0	0	602	0
2	3	12	36	—	—	—	422	9	0	422	0	0	213	209	0
2	5	13–15	24–72	—	—	—	298	3	298	0	0	0	149	149	0
2	6	16–17	72–96	—	—	—	600	24	0	0	600	0	315	252	33
2	5	18–29	27–36	—	—	—	738[6]	12	0	738	0	0	222	421	95
2	7	30–34	24–44	—	—	—	442[6]	8	0	380	62	4	265	158	15
2	8	35–44	34–84	—	—	—	751[6]	11	0	751	0	5	298	413	35

[1]Total number of observations: Exp. 1 = 1,155; Exp. 2 = 4,204.

[2]Numbered and presented in chronological order.

[3]Grading time is the time (h) interval between slaughter and grading, which varies for a variety of reasons including nonproduction days (weekends, holidays) and process differences among plants.

[4]Each VISNIR system logged the time of collection of each spectra. Clocks were synchronized on the systems to facilitate accurate calculation of the time differential between spectra collection at the time of ribbing (Unit 5015) and spectra collection at the grading stand (Unit 5016).

[5]For Exp. 2, spectra collection and tenderness prediction were made with a single instrument at a location in the grading process (bloom chain shortly before indexer, grading stand, or shortly after the grading stand) at which carcasses were accessible and in a manner that did not interfere with the routine activities of the packing plant.

[6]Cattle originated from the US Meat Animal Research Center (Clay Center, NE).

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evaluation. Items that needed to be optimized included the following: 1) changing the spectrophotometer from a 3-detector system to a single-detector system; 2) reducing the height of the sampling head so that it would easily fit into the gap between the forequarter and the hindquarter of ribbed beef carcasses; 3) adding a trigger to the sampling head; 4) adding a feedback indicator light to the sampling head; and 5) increasing the length of the fiber optic cable from 2 m to 4 m. Additionally, a limitation to the commercial adoption of that system was that the predicted slice shear force (**SSF**) value was affected by the length of time that the ribeye (LM) was exposed to air (bloomed) before evaluation (Shackelford et al., 2005). That is, if the same ribeye was evaluated after 2 min or 15 min of bloom, the resulting predicted SSF value would be different. One solution to this dilemma would be to tightly control the length of bloom time before evaluation, as was done previously (Shackelford et al., 2005, 2012). However, that would be difficult to accomplish in large-scale beef packing plants. The more desirable approach would be to have a tenderness prediction model that is unbiased by bloom time. Therefore, the present experiments were conducted to field test a system optimized for online VISNIR-based prediction of beef LM tenderness and to develop and validate a model for prediction of tenderness that would be unbiased by normal variation in bloom time before application of VISNIR.

MATERIALS AND METHODS

For those carcasses originating from US Meat Animal Research Center (**USMARC**) animals, animal procedures were reviewed and approved by the USMARC Animal Care and Use Committee. However, most of the carcasses sampled in this experiment did not involve animals originating from or under the control of USMARC (Table 1).

Spectroscopy Systems

Two identical spectroscopy systems (Unit 5015 and Unit 5016) were custom made for tenderness prediction (ASD Inc., Boulder, CO). Whereas the spectrophotometer used by Shackelford et al. (2005, 2012) sampled the wavelength range from 350 to 2,500 nm using a 3-detector system, the spectrometer in the present systems used a single detector to sample the wavelength range from 350 to 1,050 nm. This change was made because no additional tenderness prediction information was gained from the longer wavelengths (i.e., 1,000 to 2,500 nm; Shackelford et al., 2005, 2012) and changing from a 3-detector system to a single-detector system allowed for a substantial increase in speed (sampling time was reduced from 7 to 1.4 s) and a decrease in cost (cost of the spectrophotometer was decreased approximately 50%). These systems contained a sampling head that was functionally similar (i.e., same light source, same sampling area, same geometrical orientation of the fiber optic cable) to the head used by Shackelford et al. (2005, 2012). However, the head was reconfigured so that the handle was oriented in a manner that allowed the sampling head to easily fit into the gap between the forequarter and the hindquarter of ribbed beef carcasses. The handle contained a trigger that allowed the operator to easily collect spectra on moving carcasses

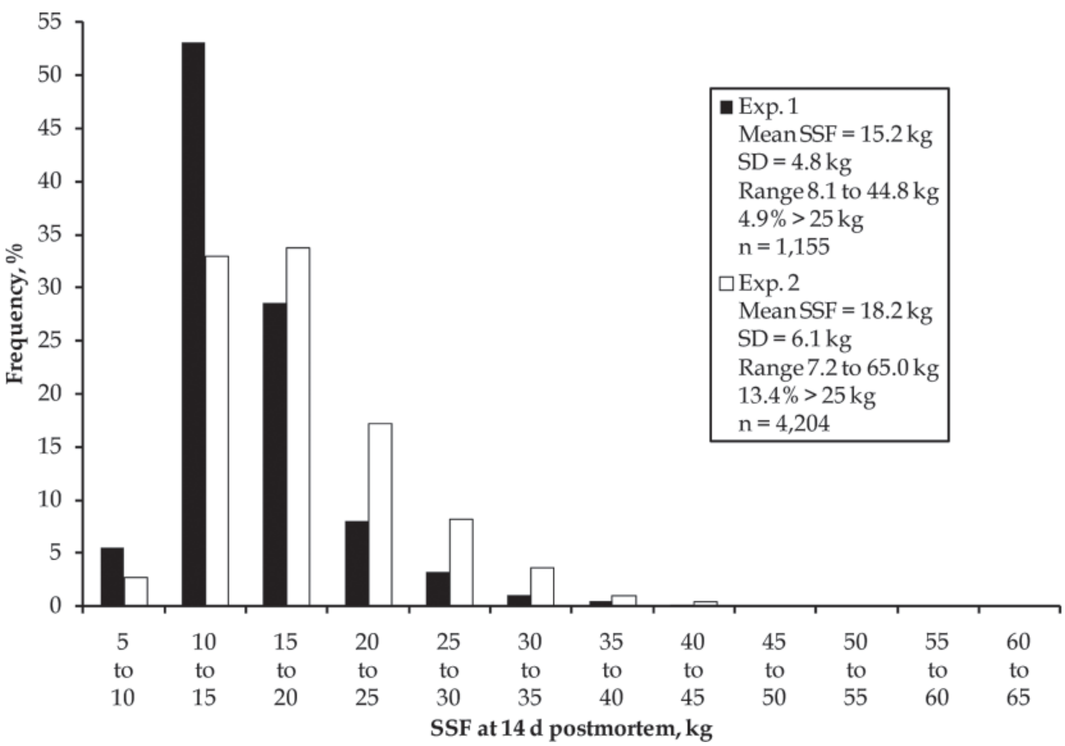

Figure 1. Frequency distributions of slice shear force (SSF) values for Exp. 1 and 2.

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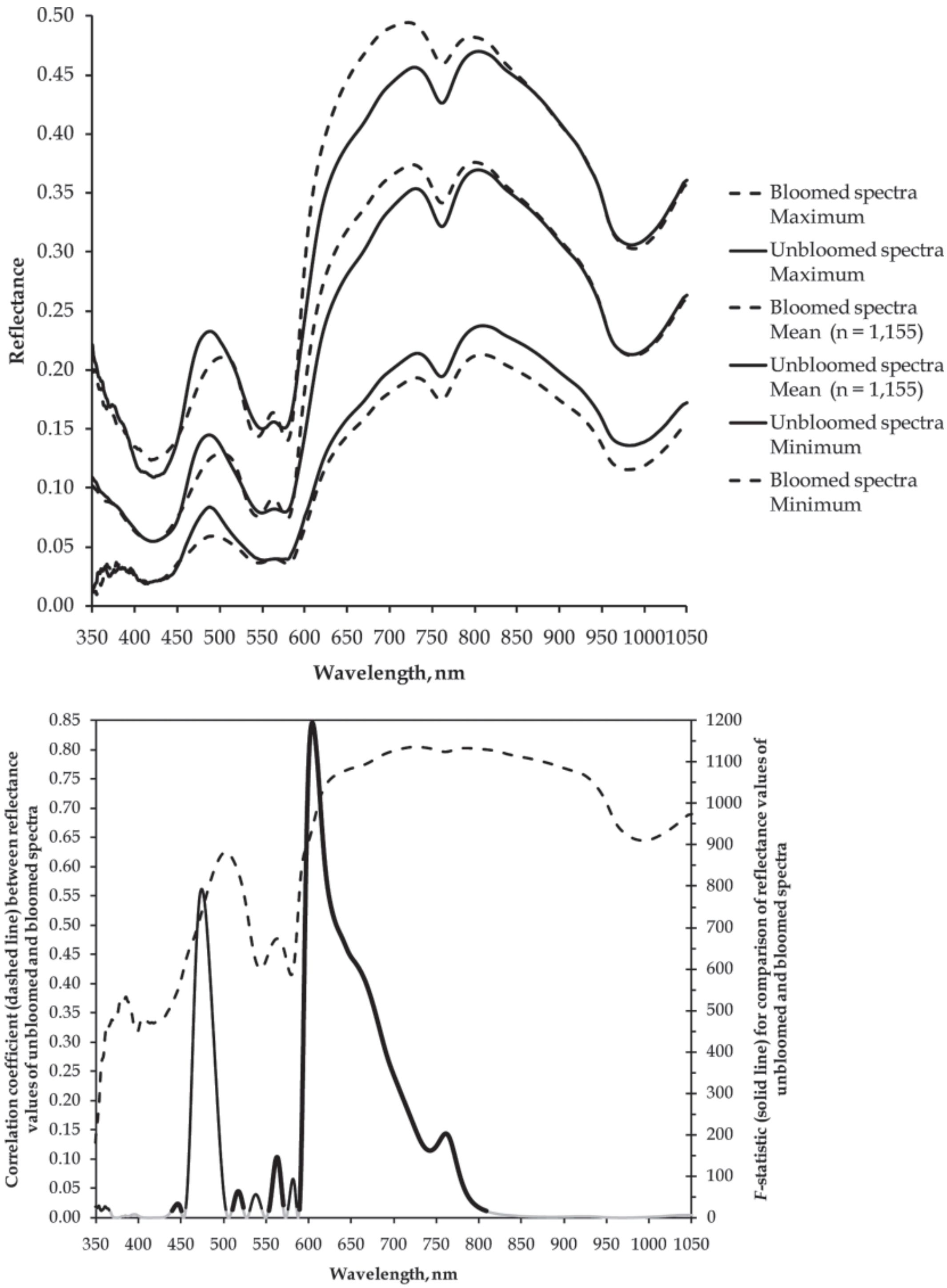

Figure 2. Top panel: Effect of bloom time on reflectance. Unbloomed spectra were collected at ribbing and bloomed spectra were collected at grading. The top pair of lines is the maximum reflectance observed among the samples, the middle pair of lines is the mean reflectance observed among the samples, and the bottom pair of lines is the minimum reflectance observed among the samples. Bottom panel: Correlation coefficient (dashed line) between reflectance values of unbloomed and bloomed spectra and F-statistic (solid line) for comparison of reflectance values of unbloomed and bloomed spectra. Black portions of the solid line indicate $P < 0.0001$.

and a light-emitting diode that provided feedback from the laptop to the sampling head, allowing the operator to know that the spectra collection had been initiated (light on) and completed (light off). Whereas the previous system (Shackelford et al., 2005, 2012) collected light with a 2-m-long fiber optic cable, the present systems collected light with a 4-m-long fiber optic cable that allowed the operator to have a greater range of operation and decreased the requirement for the spectrophotometer to be extremely close to the point of operation.

Exp. 1

Spectroscopy and Carcass Selection. Spectroscopy was conducted online at 3 commercial fed-beef

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processing facilities. During the course of the routine carcass grading procedures of each plant, the LM of the left side of each carcass was evaluated with Unit 5015 immediately after the carcass side was ribbed and the LM of the left side of each carcass was evaluated with Unit 5016 as the carcass passed the grading stand of the plant. Because of variation in the production process both among and within plants, the length of time between when carcass sides were ribbed (and evaluated by Unit 5015) and when the carcass sides passed the grading stand (and were evaluated by Unit 5016) was highly variable. Likewise, the length of time between when the cattle were slaughtered and when the carcass sides were presented for grading was variable. This information is summarized in Table 1.

After spectroscopy and grading, carcasses were fabricated and a section (15 cm long) of the anterior end (i.e., 13th rib to 3rd lumbar vertebrae) of the NAMP 180 strip loin (North American Meat Processors Association, 2010) was obtained from the left side of each carcass (n = 1,155). Vacuum-packaged strip loin sections were transported (1°C) to the USMARC abattoir, unpackaged, trimmed of subcutaneous fat, repackaged, and aged until 14 d postmortem. On d 14, a steak (2.54 cm thick) was removed from the anterior end of each strip loin and cooked from the fresh (never frozen) state using a belt grill (Wheeler et al., 1998), and SSF was measured (Shackelford et al., 1999a,b).

Statistical Analysis. For model development and validation, carcasses were blocked by plant and observed SSF. One-half of the carcasses (n = 579) were assigned to a calibration data set, which was used to develop regression equations, and one-half of the carcasses (n = 576) were assigned to a prediction data set, which was used to validate the regression equations (Neter et al., 1989). The model was developed using the PLS1 procedure (The Unscrambler, CAMO Software AS, Oslo, Norway). Spectra were pretreated with The Unscrambler's modify, transform, smoothing, moving average routine with the segment size set to 9. Model validation used the test set method using the prediction data set as described previously. The number of principal components was set at 20, which meant that model selection could have included up to 20 principal components. The X-variable weights were set to 0 for 350 to 449 nm and 1,001 to 1,050 nm. Carcasses with VISNIR-predicted SSF ≤15 kg were classified as VISNIR predicted tender and carcasses with VISNIR-predicted SSF >15 kg were classified as VISNIR not predicted tender. One-way ANOVA for differences among VISNIR tenderness classes in observed SSF at 14 d postmortem was conducted using the GLM procedure (SAS Inst. Inc., Cary, NC). The frequency of carcasses with SSF values >25 kg was calculated for each VISNIR class. Differences in these frequencies among VISNIR classes were compared using the DIFFER program of PEPI (USD Inc., Stone Mountain, GA).

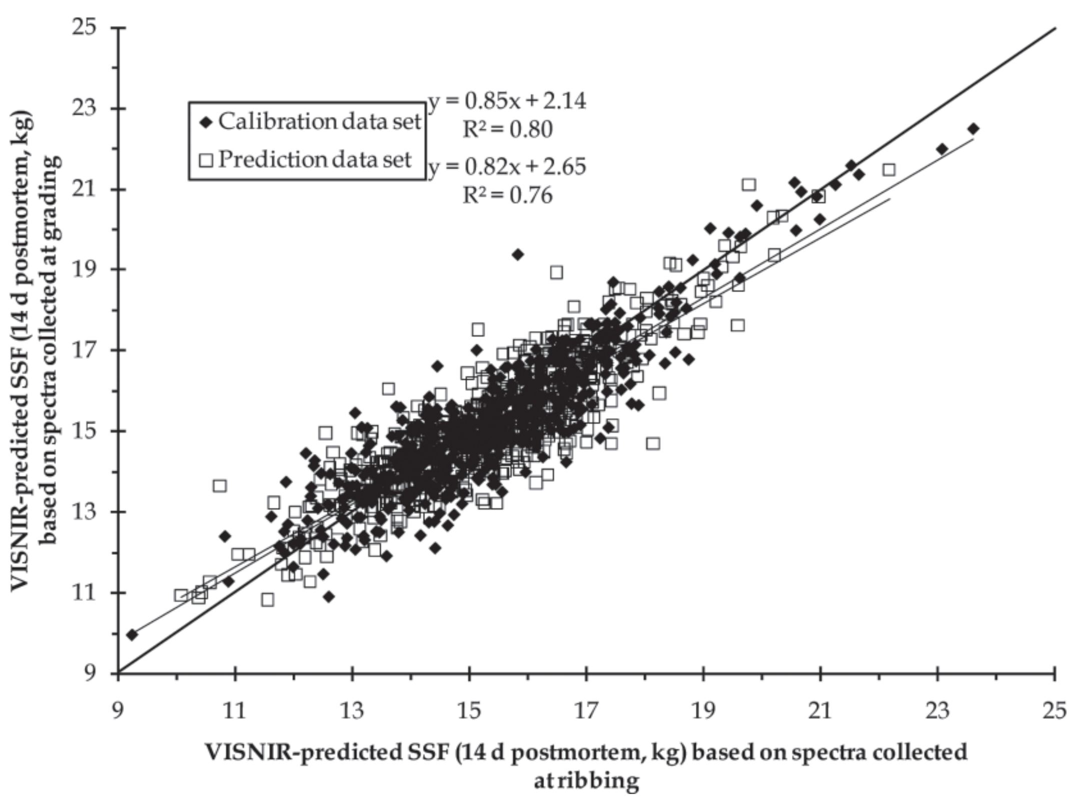

Figure 3. Relationship among visible and near-infrared (VISNIR) spectroscopy-predicted slice shear force (SSF) based on spectra collected at ribbing to the VISNIR-predicted SSF based on spectra collected at the grading stand.

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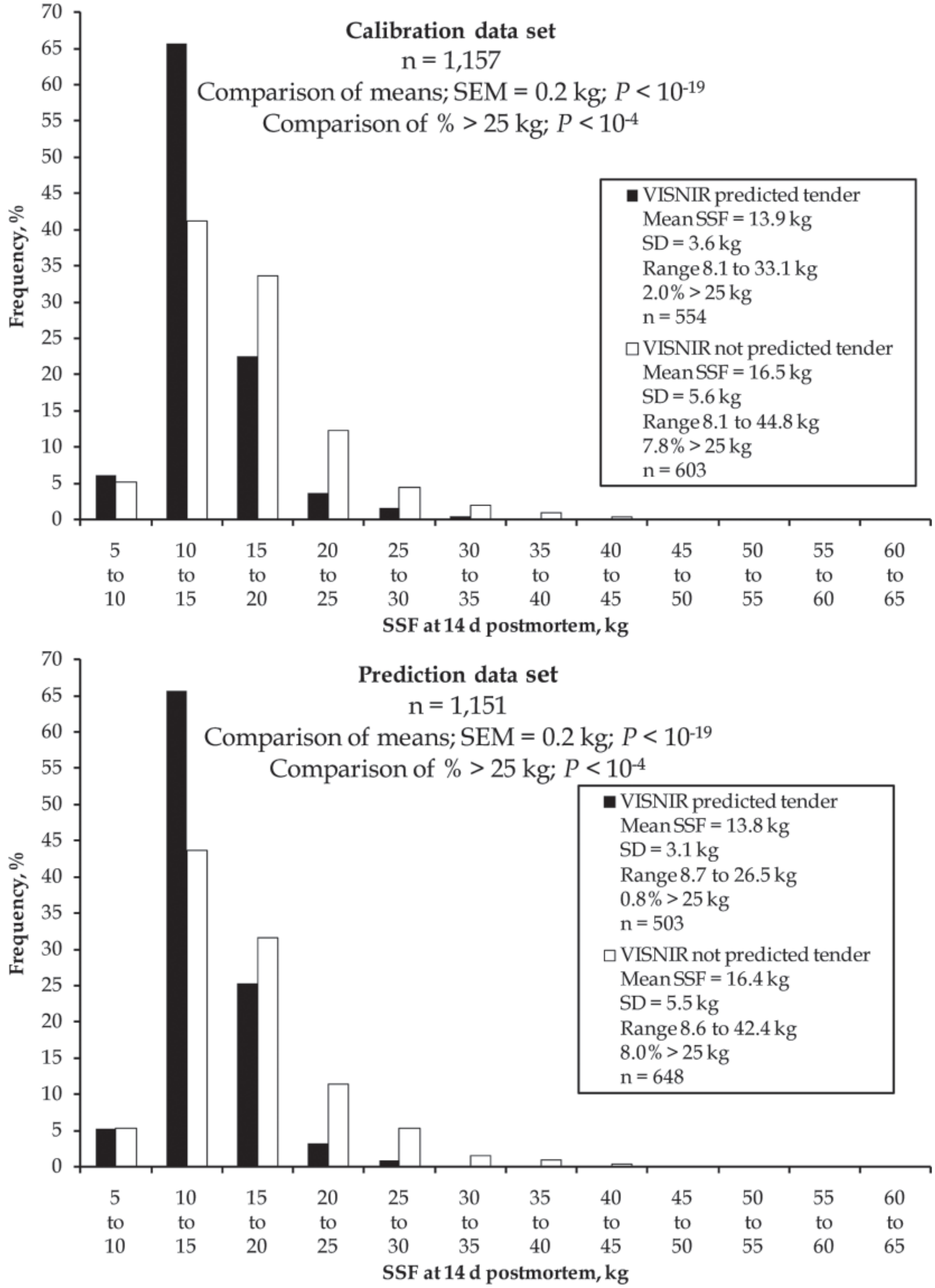

Figure 4. Experiment 1. Effect of sorting carcasses into predicted tenderness classes using online visible and near-infrared (VISNIR) spectroscopic evaluation on LM slice shear force (SSF) at 14 d postmortem. Carcasses with VISNIR-predicted SSF $\leq$15 kg were classified as VISNIR predicted tender. Top panel: The calibration data set that was used to develop the model and that contained spectra collected at both ribbing and grading for 559 carcasses. Bottom panel: The prediction data set that was used to validate the model and that contained spectra collected at both ribbing and grading for 556 carcasses.

Exp. 2

Spectroscopy and Carcass Selection. Spectroscopy was conducted online at 6 commercial fed-beef processing facilities on 38 production days (Table 1). During the course of the routine carcass-grading procedures of each plant, the LM of the left side of each carcass (n = 4,204) was evaluated with either Unit 5016 or Unit 5015 and SSF was predicted with the model developed in Exp 1. Tenderness prediction was made at a location in the grading process (on the bloom chain shortly before indexer, at the grading stand, or shortly

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Table 2. Effects of altering the acceptance threshold used for classifying carcasses into visible and near-infrared (VISNIR)-predicted tenderness classes (Exp. 2; n = 4,204)

VISNIR-predicted slice shear acceptance threshold, kg	Carcasses that were accepted tender by VISNIR, %	Accepted carcasses with observed LM slice shear force >25 kg at 14 d postmortem, %	Tough[1] carcasses that were rejected by VISNIR, %
≤12	3.0	0.8	99.8
≤13	10.1	1.7	98.8
≤14	25.3	3.0	94.3
≤15	48.5	4.9	82.2
≤16	72.1	7.7	58.7
≤17	88.5	10.2	32.4
≤18	94.9	11.7	17.3
≤19	97.3	12.4	9.4
≤20	98.5	12.9	5.0
≤21	99.0	13.0	3.4
≤22	99.4	13.2	1.6

[1]Observed LM slice shear force >25 kg at 14 d postmortem; n = 562.

after the grading stand) at which carcasses were accessible and in a manner that did not interfere with the routine activities of the packing plant. Carcasses were sourced from mill run sources and structured sources, including a variety of commercial and USMARC production trials.

After spectroscopy and grading, carcass sides were placed on stationary rails and a steak (2.54 cm thick) was obtained from the caudal end of the strip loin (13th rib) of the left side of each carcass. Steaks were tagged, packaged, transported, and stored in a manner that allowed the steaks to maintain thickness through aging. At 14 d postmortem, steaks were trimmed of subcutaneous fat and cooked from the fresh (never frozen) state using a belt grill (Wheeler et al., 1998), and SSF was measured (Shackelford et al., 1999a,b).

Exp. 2A: Application to US Choice. A subset of the carcasses (n = 422) sampled in Exp. 2 were sampled from lots in a manner such as to allow an unbiased comparison of the efficacy of the VISNIR system in US Choice and US Select, which differ primarily in the level of marbling (USDA, 1997). On d 12 (Table 1), carcasses were sampled from 9 lots at plant 3. Fifty percent of the carcasses sampled from a given lot were US Choice and 50% of the carcasses sampled from a given lot were US Select.

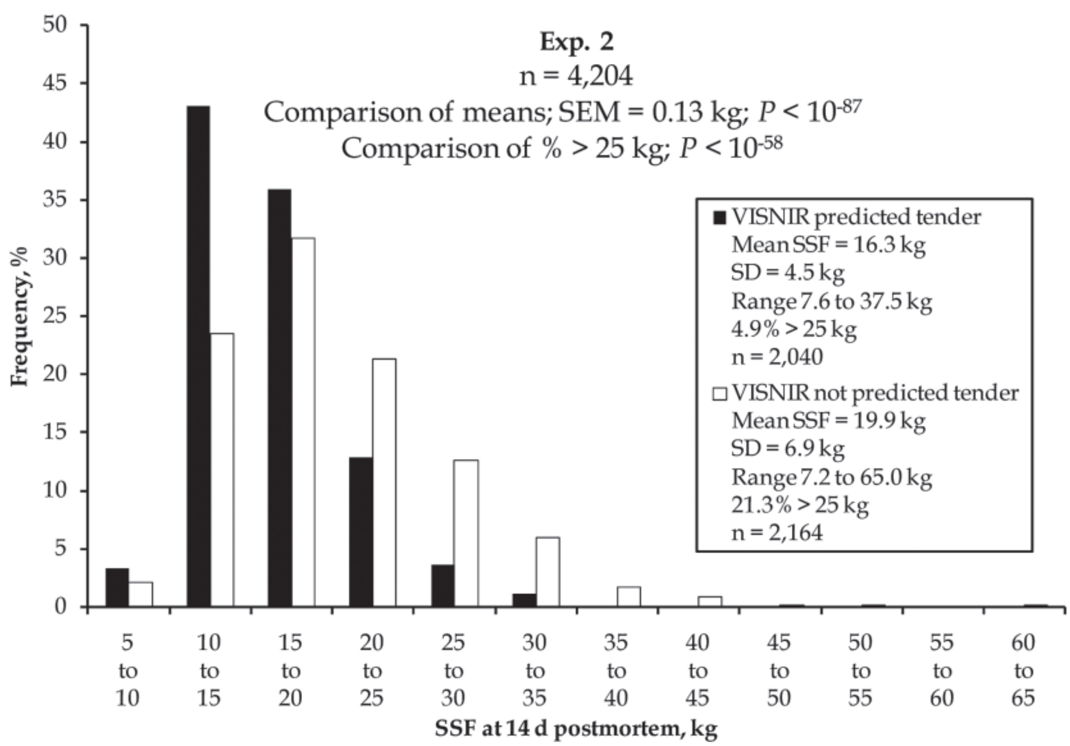

Figure 5. Experiment 2. Effect of sorting carcasses into predicted tenderness classes using online visible and near-infrared (VISNIR) spectroscopic evaluation on LM slice shear force (SSF) at 14 d postmortem (SEM = 0.13 kg). Carcasses with VISNIR-predicted SSF ≤15 kg were classified as VISNIR predicted tender. Spectroscopy was conducted online at 6 commercial fed-beef processing facilities on 38 production days.

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Exp. 2B: Biochemical Basis for VISNIR Tenderness Sorting. After SSF measurement of the carcasses sampled on d 16 and 17 (n = 600), remnants of the slice (i.e., the portion of the cooked LM steak that was sampled for SSF) were frozen for subsequent measurement of sarcomere length and postmortem proteolysis. Sarcomere length was assessed by laser diffraction using the procedure of Cross et al. (1981), and postmortem proteolysis was assessed by measuring the extent of degradation of desmin by Western blotting as described by Wheeler et al. (2002).

Statistical Analysis. Carcasses with VISNIR-predicted SSF ≤15 kg were classified as VISNIR predicted tender and carcasses with VISNIR-predicted SSF >15 kg were classified as VISNIR not predicted tender. One-way ANOVA for differences among VIS-

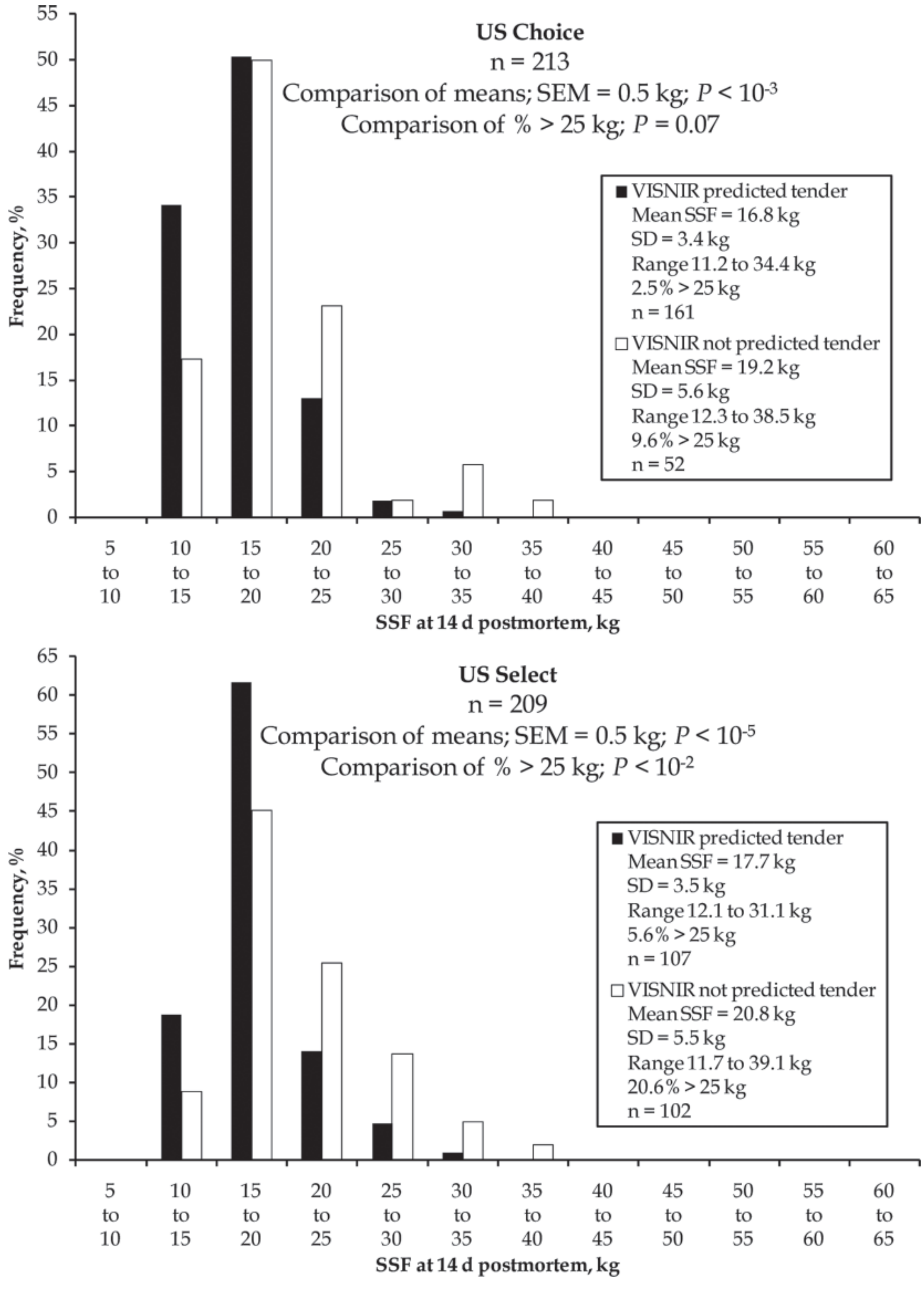

Figure 6. Experiment 2A. Effect of sorting carcasses into predicted tenderness classes using online visible and near-infrared (VISNIR) spectroscopic evaluation on LM slice shear force (SSF) at 14 d postmortem. Top panel: US Choice. Bottom panel: US Select.

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NIR tenderness classes in observed SSF at 14 d postmortem was conducted using the GLM procedure of SAS. The frequency of carcasses with SSF values >25 kg was calculated for each VISNIR class. Differences in these frequencies among VISNIR classes were compared using the DIFFER program of PEPI (USD Inc.).

RESULTS AND DISCUSSION

Exp. 1

The present data set contained ample variation in SSF at 14 d postmortem for model development (Figure 1). However, the mean SSF and the variation in

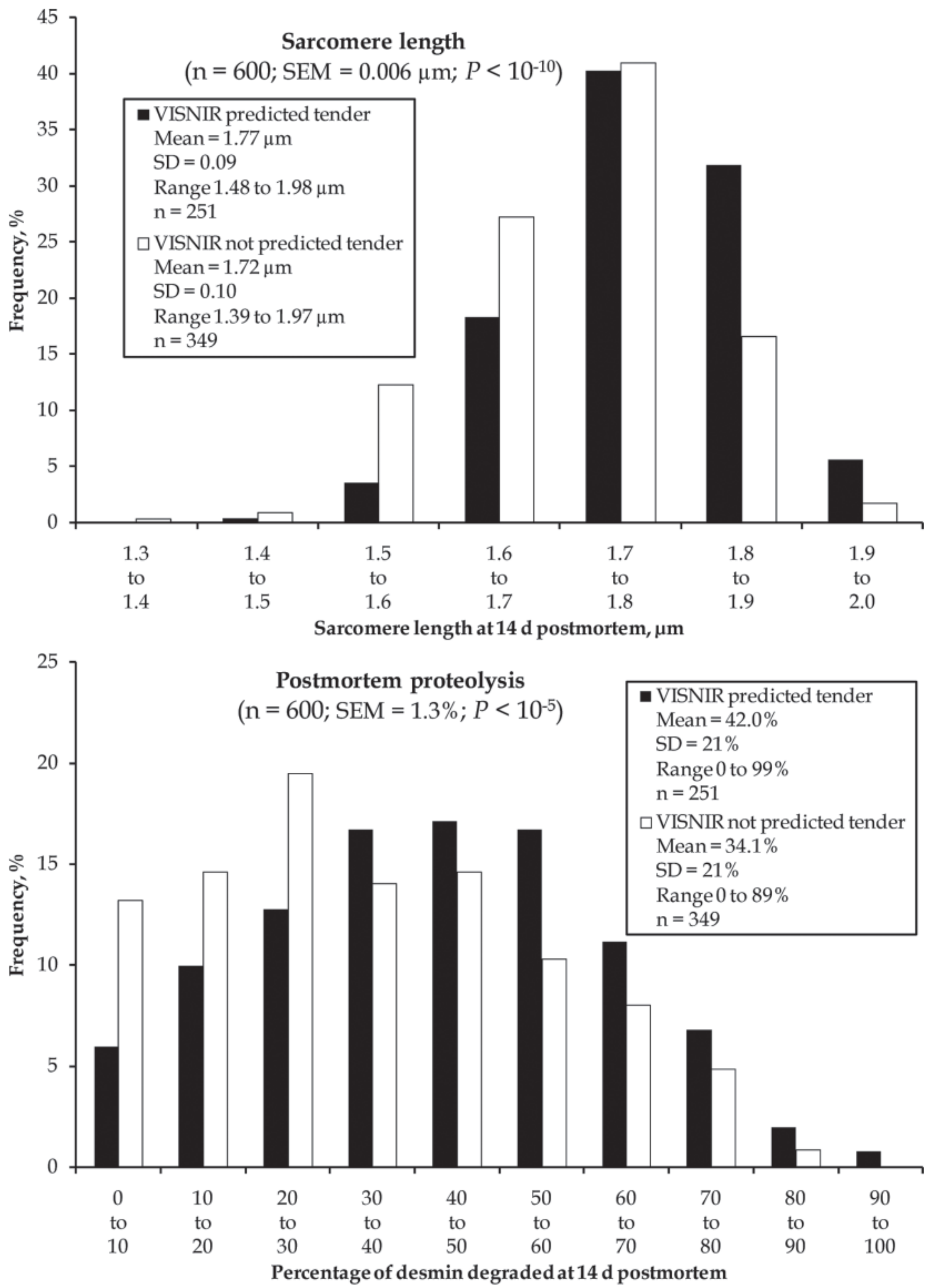

Figure 7. Experiment 2B. Effect of sorting carcasses into predicted tenderness classes using online visible and near-infrared (VISNIR) spectroscopic evaluation on biochemical characteristics of LM at 14 d postmortem. Top panel: sarcomere length. Bottom panel: the extent of postmortem proteolysis.

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Table 3. Effect of sorting carcasses (Exp. 2B) into predicted tenderness classes based on visible and near-infrared (VISNIR) spectroscopy on the frequency distribution of sarcomere length × postmortem proteolysis bins

Postmortem proteolysis class[1]	Sarcomere length class[2]	VISNIR predicted tender, %	VISNIR not predicted tender, %
Low	Short	18	32
Low	Long	23	25
High	Short	20	28
High	Long	40	16

[1]Low and high postmortem proteolysis classes contained carcasses that had lesser and greater, respectively, percentage of desmin degraded than the mode (36.7%).

[2]Short and long sarcomere length classes contained carcasses that had sarcomere lengths that were shorter and longer, respectively, than the mode (1.745 μm).

SSF were less than that observed in Exp. 2 and in previous VISNIR studies (Shackelford et al., 2005, 2012), likely because of differences in genetics, management, and postmortem handling. As expected (Shackelford et al., 2004), time after ribbing before VISNIR evaluation altered the shape of reflectance spectra curves (Figure 2). Reflectance values were greater ($P < 0.0001$) at 439 to 450, 510 to 523, 553 to 570, and 589 to 809 nm for spectra collected on bloomed LM at the grading stand compared with spectra collected on unbloomed LM shortly after ribbing. Reflectance values were reduced ($P < 0.0001$) at 350 to 366, 456 to 503, 531 to 545, and 576 to 586 nm for spectra collected on bloomed LM at the grading stand compared with spectra collected on unbloomed LM shortly after ribbing. For each wavelength, reflectance values were positively correlated ($P < 0.0001$) among spectra collected on bloomed LM at the grading stand and spectra collected on unbloomed LM shortly after ribbing. The strength of that correlation was maximal (0.81) at 726 nm and minimal (0.13) at 350 nm.

Whereas the previous VISNIR-based system for tenderness prediction used 10 variables, the optimum partial least squares model obtained in the present study contained 2 principal components. The difference in the number of components included in these models may be a function of the method of model development used in this study. In this study, each carcass was represented as 2 observations. One observation used the spectra collected on unbloomed LM and one observation used the spectra collected on bloomed LM. This approach strongly favored the selection of a regression equation that was unbiased by bloom time. A comparison of the VISNIR-predicted SSF based on spectra collected at ribbing with the VISNIR-predicted SSF based on spectra collected at the grading stand, using 1-way ANOVA and simple correlation, showed them to be similar and highly correlated in both the calibration ($P = 0.14$; $R^2 = 0.80$) and prediction ($P = 0.11$; $R^2 = 0.76$) data sets (Figure 3). That is, the goal of developing a regression equation that was not biased by bloom time was achieved.

Online VISNIR tenderness classes differed in mean LM SSF values at 14 d postmortem in the calibration and prediction data sets (Figure 4; $P < 10^{-19}$; $R^2 = 0.14$; root mean square error = 4.4 kg). Online VISNIR tenderness classes differed in the percentage of carcasses with LM SSF values >25 kg at 14 d postmortem ($P < 10^{-4}$). The similarity of results between the calibration and prediction data sets suggested that this model was robust. However, given the relatively low frequency of tough samples (SSF >25 kg) in Exp. 1, Exp. 2 was conducted to verify the robustness of this model.

Exp. 2

Online VISNIR tenderness classes differed in mean LM SSF values at 14 d postmortem in Exp. 2 (Figure 5; $P < 10^{-87}$). Online VISNIR tenderness classes differed in the percentage of carcasses with LM SSF values >25 kg at 14 d postmortem ($P < 10^{-58}$). These data demonstrate the robustness of this system for prediction of tenderness when applied to a large sample of carcasses processed in 6 commercial packing plants over 38 production days spanning a 5-yr period. These carcasses originated from animals of diverse genetics and management regimens and were processed under a variety postmortem processing schemes.

Threshold for Acceptance. In the previous analyses (Exp. 1 and 2), the threshold for acceptance ("predicted tender") was a VISNIR-predicted SSF value of SSF ≤15 kg. The effect of changing the threshold for acceptance would be significant (Table 2). If this value was raised from 15 to 16 kg, the proportion of the carcasses in Exp. 2 meeting the threshold for acceptance would increase from 48.5 to 72.1%. But, at the same time, the percentage of the accepted carcasses with observed LM SSF >25 kg at 14 d postmortem would increase from 4.9 to 7.7%. This data set contained 562 "tough" carcasses (observed LM SSF at 14 d postmortem >25 kg). With the threshold for acceptance set at 15 kg, 82.2% of those tough carcasses would have been rejected by VISNIR. If the threshold for acceptance was raised to 16 kg, 58.7% of those tough carcasses would have been rejected by VISNIR. If the threshold for acceptance was raised to 17 kg, only 32.4% of the tough carcasses would have been rejected by VISNIR. Clearly, tradeoffs between supply of accepted product

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and the tenderness consistency of the accepted product will have to be considered in the selection of the threshold for acceptance.

Exp. 2A: Application to US Choice. Most of the carcasses sampled in Exp. 1 were US Select. Emphasis was placed on US Select because of the potential economic rewards associated with identifying consistently tender Select carcasses (Shackelford et al., 2001). Some companies may also want to apply this technology to US Choice. However, the efficacy of this system in US Choice was not known. Compared with US Select, a greater percentage of US Choice carcasses were classified as tender by VISNIR (Figure 6; 161/213 = 76% vs. 107/209 = 51%; $P < 10^{-6}$). Online VISNIR tenderness classes differed in mean LM SSF values at 14 d postmortem in both US Choice ($P < 10^{-3}$) and US Select ($P < 10^{-5}$). Whereas 20.6% of US Select carcasses that were not classified as tender by VISNIR had LM SSF values >25 kg at 14 d postmortem, 5.6% of US Select carcasses that were classified as tender by VISNIR had LM SSF values >25 kg at 14 d postmortem ($P < 0.01$). Whereas 9.6% of US Choice carcasses that were not classified as tender by VISNIR had LM SSF values >25 kg at 14 d postmortem, only 2.5% of US Choice carcasses that were classified as tender by VISNIR had LM SSF values >25 kg at 14 d postmortem ($P = 0.07$). These data show that this system is an effective means to noninvasively classify US Choice carcasses for LM tenderness. Rust et al. (2008) studied an off-line near-infrared system and determined that it was capable of tenderness sorting across quality grades (i.e., a pool of US Select and US Choice carcasses); however, it is unclear from their report whether the system was efficacious within US Choice.

Exp. 2B: Biochemical Basis for VISNIR Tenderness Sorting. To gain insight into the biochemical basis for VISNIR tenderness sorting, sarcomere length and postmortem proteolysis were compared among VISNIR-predicted tenderness classes. For LM of carcasses classified as tender by VISNIR, sarcomeres were longer ($P < 10^{-10}$) and the extent of degradation of desmin at 14 d postmortem was greater ($P < 10^{-5}$; Figure 7). Twice as many of the carcasses that were classified as tender by VISNIR had both an increased (>mode) level of proteolysis and long (>mode) sarcomere lengths as had both a decreased level of proteolysis and short sarcomere lengths (40% vs. 18%; Table 3). In contrast, twice as many of the carcasses that were not classified as tender by VISNIR had both a decreased (<mode) level of proteolysis and short (<mode) sarcomere lengths as had both an increased level of proteolysis and long sarcomere lengths (32% vs. 16%). Collectively, these data indicate that the biochemical basis for tenderness sorting with VISNIR includes both postmortem proteolysis and sarcomere length.

General Discussion

The present experiments resulted in development and independent validation of a robust method to noninvasively predict LM tenderness of grain-fed beef carcasses. This technology could facilitate tenderness-based beef merchandising systems. Additional work is needed to determine the effect of this tenderness sorting technology on variation in tenderness of other muscles.

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