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Development of a system for classification of pork loins for tenderness using visible and near-infrared reflectance spectroscopy[1,2]

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ABSTRACT: Boneless pork loins (n = 901) were evaluated either on the loin boning and trimming line of large-scale commercial plants (n = 465) or at the US Meat Animal Research Center abattoir (n = 436). Exposed LM on the ventral side of boneless loins was evaluated with visible and near-infrared spectroscopy (VISNIR; 450 to 1,000 nm) using a commercial system that was developed for on-line evaluation of beef tenderness. Boneless loin sections were aged (2°C) until 14 d postmortem, and two 2.54-cm-thick chops were obtained from the 11th-rib region. Fresh (never frozen) chops were cooked (71°C) and LM slice shear force (SSF) was measured on each of the 2 chops. Those 2 values were averaged, and that value was used for all analyses. Loins were blocked by plant (n = 3), production day (n = 24), and observed SSF (mean = 13.9 kg; SD = 3.7 kg; CV = 26.8%; range 6.4 to 32.4 kg). One-half of the loins were assigned to a calibration data set, which was used to develop regression equations, and one-half of the loins were assigned to a prediction data set, which was used to validate the regression equations. A partial least-squares regression model was developed, and loins were classified as predicted tender or not predicted tender if their VISNIR-predicted SSF was <14.0 kg or ≥14.0 kg, respectively. Analysis of variance was used to determine the effect of VISNIR classification on SSF. The calibration data set and prediction data set had 61.9 and 60.9% of the loins classified as predicted tender, respectively. For both the calibration data set and the prediction data set, mean SSF was less for loins predicted tender than loins not predicted tender ($P < 0.001$). Relative to loins that were not predicted tender, the percentage of loins with SSF ≥20 kg was less for loins predicted tender in the calibration data set (3.6 vs. 8.1%) and prediction data set (1.8 vs. 13.6%). These results clearly indicate that the VISNIR technology could be used to noninvasively classify pork loins on-line for tenderness.

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

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INTRODUCTION

Moeller et al. (2009) reported a strong relationship between Warner-Bratzler shear force and consumer liking ratings of nonenhanced and enhanced pork loins. Consequently, there has been interest in developing retail programs based on quality. As the pork industry moves toward selling products at retail based on quality ("Guaranteed Tender" programs and other high-quality programs), being able to differentiate carcasses of better quality becomes more important (Holmer and Sutton, 2009). Thus, there has been interest in implementing a means to identify pork that is superior in tenderness. A system for on-line classification of beef carcasses for LM tenderness using visible and near-infrared (**VISNIR**) reflectance spectroscopy has been developed and validated [Shackelford et al., 2004a, 2005; S. D. Shackelford, T. L. Wheeler, D. A. King, and M. Koohmaraie (IEH Laboratories and Consulting Group, Lake Forest Park, WA), unpublished data; S. D. Shackelford, T. L. Wheeler, and M. Koohmaraie (IEH Laboratories and Consulting Group, Lake Forest Park, WA), unpublished data]. That system involved evaluation of the cut surface of LM of ribbed beef carcasses. A challenge to implementing that system for the evaluation of pork was that pork carcasses are not normally ribbed commercially. However, in boneless

[1]Mention of trade names, proprietary products, or specified equipment does not constitute a guarantee or warranty by the USDA and does not imply approval to the exclusion of other products that may be suitable. The authors are grateful to Patty Beska, Kathy Mihm, Pat Tammen, Samantha Myers, Cassandra Stephenson, Leo Boman, Erin Musgrave, Adria Grayson, Juli Lacumsky, Steven Wahlmeier, and Kristin Ostdiek of the US Meat Animal Research Center for their assistance in the execution of this experiment and to Marilyn Bierman of the US Meat Animal Research Center for her secretarial assistance.

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Table 1. Number of sampling days on which loins were evaluated by visible and near-infrared (VISNIR) spectroscopy and number of loins sampled, stratified by processing plant and hog source

Days	Plant	Hog source	No. of loins sampled
1 to 6, 10 to 13, 15 to 17, 19 to 24	USMARC[1]	USMARC[1]	436
7	Commercial plant 1	Commercial	100
8	Commercial plant 2	Commercial	120
9, 14, 18	Commercial plant 1	USMARC[1]	245

[1]US Meat Animal Research Center.

loin production, the ventral side of LM is frequently exposed, particularly in the production of "meaty" back ribs. This exposed LM could potentially be evaluated by VISNIR as a means to predict tenderness and other pork quality traits; however, it was unknown whether evaluation of that lean would allow for the prediction of loin tenderness. Therefore, the present experiment was conducted to develop a noninvasive on-line method to predict tenderness of pork loins, as measured by slice shear force. A secondary objective was to determine whether this technology could be used to noninvasively predict intramuscular fat (**IMF**) content.

MATERIALS AND METHODS

For those loins originating from US Meat Animal Research Center (**USMARC**) animals, animal procedures were reviewed and approved by the USMARC Animal Care and Use Committee. Some of the loins sampled in this experiment did not involve animals originating from or under the control of USMARC (Table 1); however, all loins were from federally inspected processing facilities.

Boneless pork loins (n = 901) were evaluated either on-line on the loin boning and trimming line of large-scale commercial plants (n = 465) or at the USMARC abattoir (n = 436). Within 2 min of deboning, exposed LM on the ventral side of boneless loins was evaluated with VISNIR using a commercial system that was developed for on-line evaluation of beef tenderness. The spectroscopy system (Unit 5016) was described by S. D. Shackelford, T. L. Wheeler, D. A. King, and M. Koohmaraie (IEH Laboratories and Consulting Group, Lake Forest Park, WA), unpublished data. For all sampling days except d 9, 14, and 18, a second VISNIR evaluation was conducted on a cross-section of LM of each loin (n = 656). Sampling occurred over 2 yr and included 5, 2, 4, 5, 7, 1, and 1 d in January, April, May, June, July, August, and October, respectively.

Experimental Procedures

Boneless loin sections were vacuum-packaged and aged (2°C) until 14 d postmortem, and two 2.54-cm-thick chops were obtained from the 11th-rib region. Fresh (never frozen) chops were cooked (71°C) with a belt grill, and LM slice shear force (**SSF**) was measured on each of the 2 chops (Shackelford et al., 2004b). The duplicate SSF values were averaged, and that value was used for all analyses.

The remainder of each loin was frozen, and subsequently, a chop was obtained for assessment of IMF content. Raw LM chops were trimmed free of surface fat and epimysium and pulverized with a food processor. The pulverized sample was divided approximately in half, and duplicate random samples (approximately 70 g each) were taken, wrapped in cheesecloth, and frozen at −30°C. Moisture content was determined after samples were thawed and subjected to oven drying at 100°C for 24 h, and total lipids were obtained on dried samples by diethyl ether extraction (AOAC, 1985).

Statistical Analysis

For model development and validation, loins were blocked by plant (n = 3), production day (n = 24), and observed SSF. One-half of the loins (n = 451) were assigned to a calibration data set, which was used to develop regression equations, and one-half of the loins (n = 450) were assigned to a prediction data set, which was used to validate the regression equations (Neter et al., 1989). The SSF and IMF models were developed using the PLS1 procedure of The Unscrambler (Camo Software AS, Oslo, Norway). Spectra were not pretreated. Model validation used the test set method with the prediction data set as described above. 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 ≤14 kg were classified as VISNIR-predicted tender and carcasses with VISNIR-predicted SSF >14 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 >20 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).

RESULTS AND DISCUSSION

The optimal model for prediction of pork LM IMF contained 2 principal components. Classification of pork loins based on spectroscopic evaluation of the ventral side of LM resulted in VISNIR tenderness classes that differed in mean LM SSF values at 14 d postmortem in the calibration ($P < 10^{-3}$) and prediction ($P < 10^{-7}$) data sets (Figure 1). Relative to loins predicted to be tender by spectroscopic evaluation of the ventral side of LM, loins that were not predicted to be tender were more likely to have SSF >20 kg in the calibration

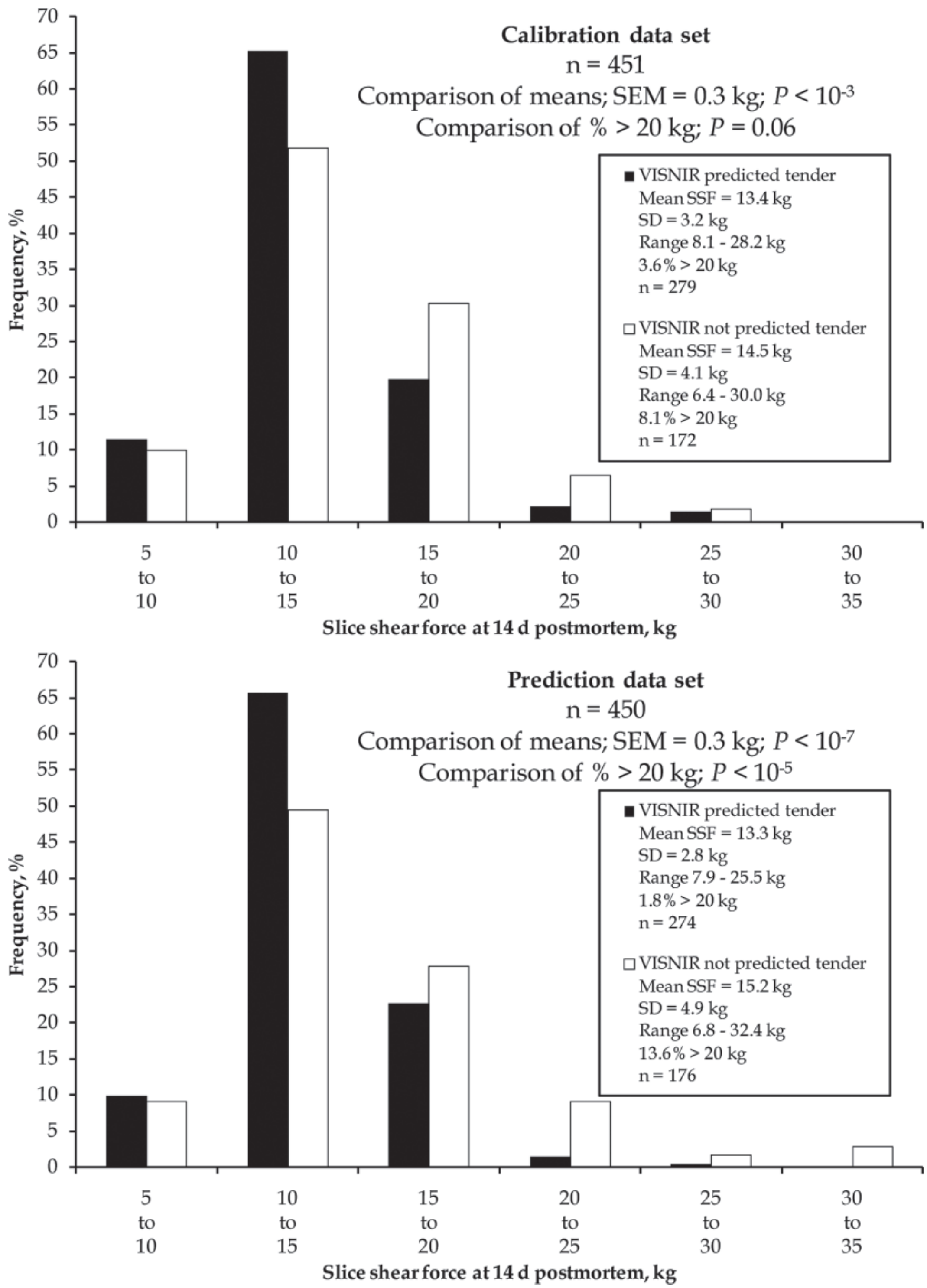

Figure 1. Effect of sorting pork loins immediately after deboning into predicted tenderness classes using visible and near-infrared (VISNIR) spectroscopic evaluation of the ventral side of LM on LM slice shear force (SSF) at 14 d postmortem. Loins with VISNIR-predicted SSF ≤14 kg were classified as VISNIR-predicted tender. The top panel shows the calibration data set (n = 451), which was used to develop the model, and the bottom panel shows the prediction data set (n = 450), which was used to validate the model.

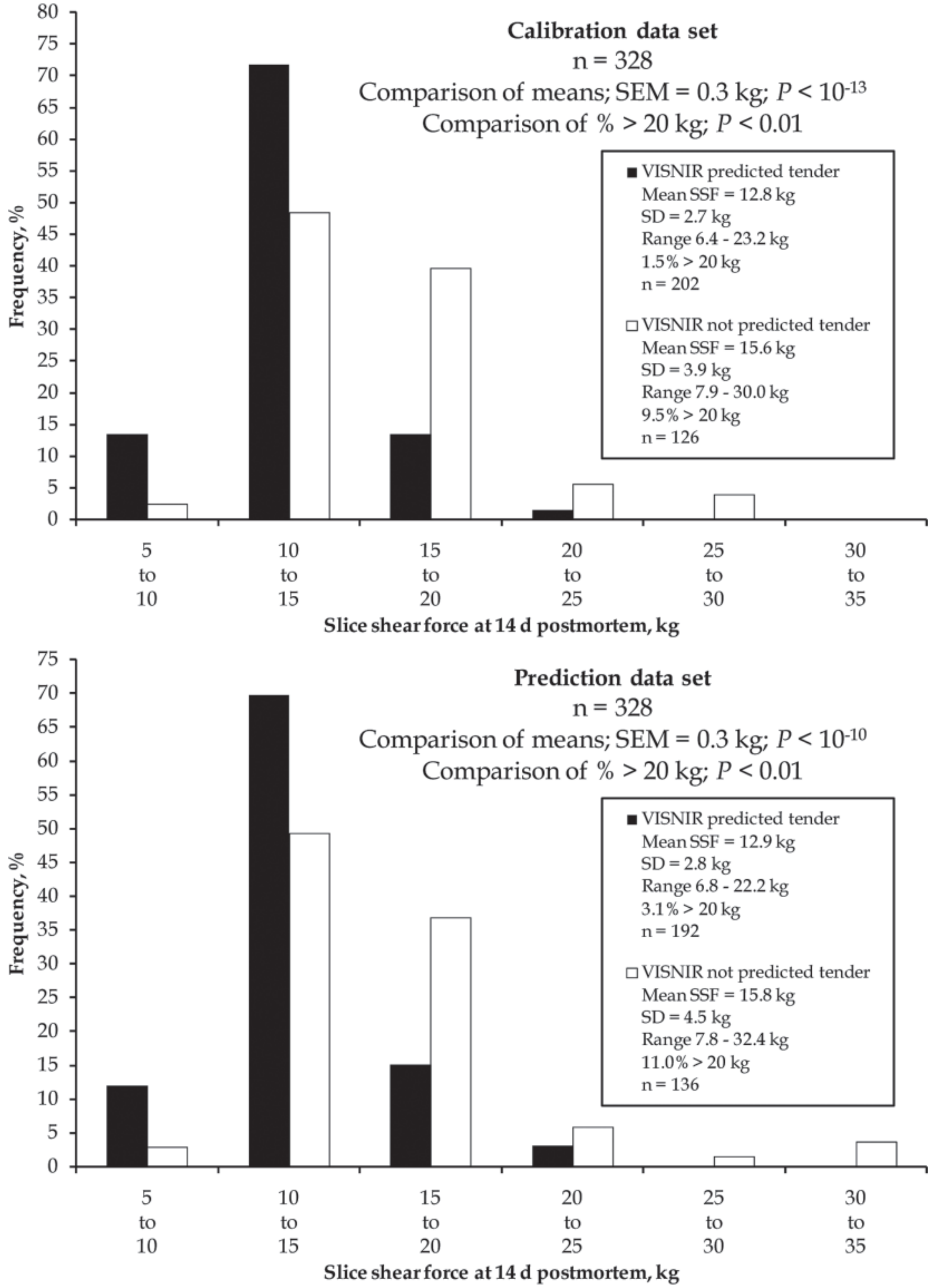

Figure 2. Effect of sorting pork loins into predicted tenderness classes using visible and near-infrared (VISNIR) spectroscopic evaluation of a cross-section of LM on LM slice shear force (SSF) at 14 d postmortem. Loins with VISNIR-predicted SSF $\leq$14 kg were classified as VISNIR-predicted tender. The top panel shows the calibration data set (n = 328), which was used to develop the model, and the bottom panel shows the prediction data set (n = 328), which was used to validate the model.

($P = 0.06$) and prediction ($P < 10^{-5}$) data sets. These data indicated that pork tenderness could be predicted by noninvasive VISNIR evaluation of the ventral side of boneless loins. The predictive accuracy observed for pork in this study was similar to that observed for VISNIR-based prediction of beef LM SSF [Shackelford et al., 2005; S. D. Shackelford, T. L. Wheeler, D. A. King, and M. Koohmaraie (IEH Laboratories and Consulting Group, Lake Forest Park, WA), unpublished data; S. D. Shackelford, T. L. Wheeler, and M. Koohmaraie (IEH Laboratories and Consulting Group, Lake Forest Park, WA), unpublished data]; however, the predictive

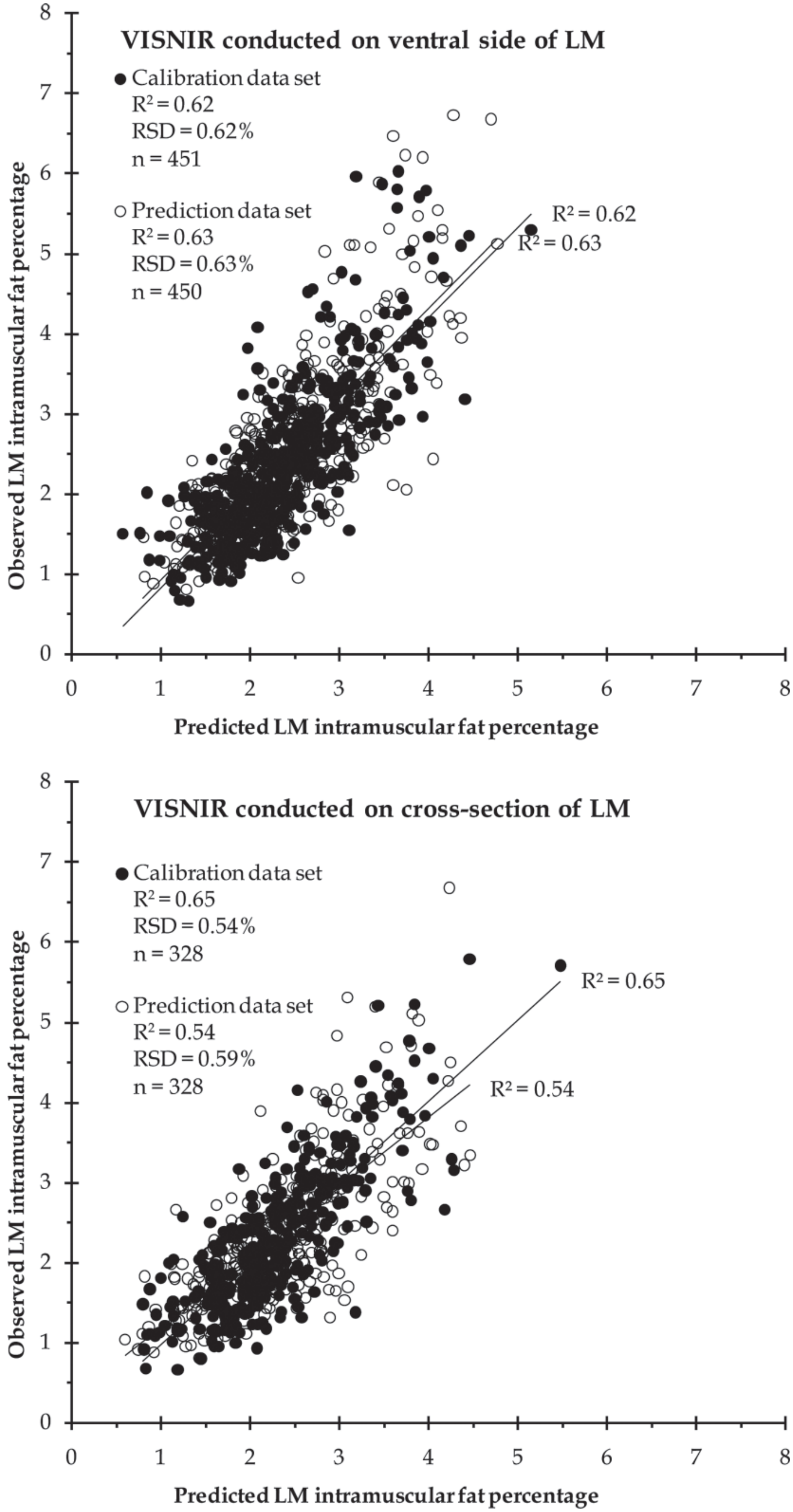

Figure 3. Prediction of pork LM intramuscular fat percentage using visible and near-infrared (VISNIR) spectroscopic evaluation of either the ventral side of LM (top panel) or a cross-section of LM (bottom panel). Each panel shows the calibration data set, which was used to develop the model, and the prediction data set, which was used to validate the model. RSD = residual SD.

models used for beef and pork differed considerably. That is, a single VISNIR-based prediction model was not capable of predicting LM tenderness across species.

Classification of pork loins based on spectroscopic evaluation of a cross-section of LM resulted in VISNIR tenderness classes that differed in mean LM SSF values at 14 d postmortem in the calibration ($P < 10^{-13}$) and prediction ($P < 10^{-10}$) data sets (Figure 2). Relative to loins predicted to be tender by spectroscopic evaluation of a cross-section of LM, loins that were not predicted to be tender were more likely to have SSF >20 kg in the calibration ($P < 0.01$) and prediction ($P < 0.01$) data sets. These data indicated that pork tenderness could be predicted by VISNIR evaluation of a cross-section of LM and that the predictive precision would be slightly greater than could be achieved by VISNIR evaluation of the ventral side of boneless loins. However, direct comparison of the statistics provided for these 2 sampling sites was not unbiased because VISNIR evaluation of a cross-section of LM was not conducted for all the loins. Additionally, the number of principal components in the optimal model for evaluation of a cross-section of LM was greater (14 vs. 2) than for evaluation of the ventral side of LM, suggesting that it was much more likely that the model for evaluation of a cross-section of LM was overspecified.

The optimal models for prediction of LM IMF-based spectroscopic evaluation of the ventral side of LM and spectroscopic evaluation of a cross-section of LM contained 9 and 17 principal components, respectively. Spectroscopic evaluation of the ventral side of LM resulted in an accurate prediction of LM IMF in the calibration ($R^2 = 0.62$; $P < 0.0001$) and prediction ($R^2 = 0.63$; $P < 0.0001$) data sets (top panel of Figure 3). Spectroscopic evaluation of a cross-section of LM resulted in an accurate prediction of LM IMF in the calibration ($R^2 = 0.65$; $P < 0.0001$) and prediction ($R^2 = 0.54$; $P < 0.0001$) data sets (bottom panel of Figure 3). Although the R^2 achieved in the prediction data set in the latter case was smaller, the residual SD was only slightly greater for the prediction data set.

Whereas there have been numerous laboratory-scale evaluations of the potential of VISNIR to predict pork quality attributes (Chan et al., 2002; Geesink et al., 2003; Hoving-Bolink et al., 2005; Monroy et al., 2010; Cai et al., 2011), to our knowledge, this is the first study of an on-line system for pork LM tenderness prediction. Moreover, a greater potential for tenderness classification with VISNIR was observed in the present study than was observed previously (Chan et al., 2002; Geesink et al., 2003). This may have been a function of instrument differences, differences in the technique used to measure tenderness, or possibly the greater sample size and sample diversity in the present study.

The present experiment resulted in the development of a method to predict LM tenderness and IMF content of pork loins noninvasively on-line. This technology could facilitate tenderness-based pork merchandising systems. Additionally, this tool could facilitate genetic evaluation studies by reducing the need for destructive and costly phenotypes, such as shear force measurement and chemical assessment of IMF.

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