Title: Prediction of pork loin quality and tenderness with the VQG pork loin grading camera - **NPB #15-103**

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Industry Summary:

The VQG pork loin grading camera was developed jointly by USDA-ARS researchers at the U.S. Meat Animal Research Center in collaboration with E+V, a company that develops and markets image analysis-based systems for the meat, poultry, and livestock industries. The VQG is applied to the ventral side of boneless pork loins to evaluate tenderness, lean color, intramuscular fat percentage, and water-holding capacity of longissimus muscle. In commercial application, this technology could be applied to loins at the end of the loin boning and trimming process to determine which loins qualify for a specific brand. However, it is likely that some processors will use this technology immediately after loin boning to facilitate real-time decision making in regards to how each loin should be trimmed to meet the needs of diverse markets. The objective of this study was to develop an accurate method to predict/evaluate meat quality traits of pork loins under industrial conditions. For this project, testing occurred on 7 production days in 6 large-scale commercial packing plants. At or near the end of the loin boning and trimming line, each test loin (n = 1,400; 7 days × 200/day) was evaluated with the VQG and serially-numbered for data collection. Most test loins were strap-off loins, which typically would have been destined for domestic markets. But, 22% of test loins were strap-on loins, which typically would have been destined for export markets. While it was not ideal to sample loins trimmed to different specifications, this was necessary to sample ample variation in lean color and marbling. Objective color and subjective color, marbling, and firmness were evaluated on the ventral side of each loin. Using a portable pH meter equipped with a stab electrode, longissimus pH was determined near both the posterior and anterior ends of the loin. Boneless loins were vacuum packaged, transported to USMARC and aged. At 14 d postmortem, loins were unpackaged and weighed for determination of purge loss. Chops were obtained from the loins and objective and subjective assessments were made on chops that were bloomed 3 h. Tenderness was assessed as slice shear force.

This technology provides the pork industry with a tool to evaluate meat quality characteristics of boneless loins at commercial processing speeds. This could be used to determine which loins qualify for a specific brand or to facilitate real-time decision making in regards to how each loin should be trimmed to meet the needs of diverse markets. The software has been designed with flexible classification settings to allow industry professionals the ability to easily tailor the system to maximize value. Values can be set to assign loins to the proposed NPB grading system. Due to a high level of interest in the VQG, trial and permanent installations will occur at packing plants owned by

multiple companies in the coming months. This tool will likely be used to facilitate genetic selection for pork quality.

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Scientific Abstract:

To develop an accurate method to predict/evaluate meat quality traits of pork loins under industrial conditions, boneless pork loins (n = 1,400; 7 days × 200/day) were evaluated with the VQG pork loin grading camera during routine loin boning and trimming. Testing occurred at 6 large-scale commercial packing plants. Using the exposed longissimus on the ventral side of the boneless loin, loins were imaged by the VQG, objective color was assessed, and subjective color, firmness, and marbling were evaluated. Longissimus pH was determined. Vacuum-packaged loins were aged until 14 d postmortem and purge loss was determined. Loins were sliced into chops and objective and subjective assessments were made on chops that had been bloomed 3 h. Longissimus pH was determined for the chops. The following d, chops were cooked and cooking loss and slice shear force were determined. One-half of the loins were assigned to a calibration (n = 700) data set, which was used to develop regression equations, and one-half of the loins were assigned to a prediction (n = 700) data set, which was used to validate the regression equations. When appropriate, data from a separate experiment (n = 7,106 loins with routine quality measurements and n = 788 loins with slice shear force data) was used to independently validate equations. Noninvasive assessment of loin muscle lean color made with the VQG immediately following loin boning and trimming was strongly correlated to objective and subjective color measurements taken on the ventral side of the boneless pork loin at the time of cutting (1 d postmortem) and measurements taken on bloomed chops at 14 d postmortem. The equation, which was developed to predict Hunter colorimeter L* with the calibration data set was effective for the prediction data set suggesting that this equation is robust. For the prediction data set, the VQG camera predictions of loin L* were negatively correlated with subjective color scores of the loin at 1 d postmortem (r = -0.55) and bloomed chops at 14 d postmortem (r = -0.50). A positive correlation occurred between the VQG camera predictions of loin color and chop L* (r = 0.78) for the prediction data set. VQG predicted intramuscular fat percentage (IMF) was correlated with observed IMF (r = 0.71 to 0.78), observed marbling score taken on the ventral side of the boneless pork loin at the time of cutting (1 day postmortem; r = 0.63 to 0.68) and observed marbling score taken on bloomed chops at 14 d postmortem (r = 0.55 to 0.69) for the calibration and prediction data sets and when validated independently. For water-holding capacity, a regression model was developed to predict cooking loss at 15 d postmortem. For the calibration and prediction data sets, predicted cooking loss was positively correlated with cooking loss (r = 0.50 to 0.62) and purge loss (r = 0.38 to 0.44) and negatively correlated with pH at 1 (r = -0.47 to -0.51) and 14 (r = -0.36 to -0.37) d postmortem. For tenderness, a regression model was developed to predict slice shear force (SSF) at 15 d postmortem. For the calibration and prediction data sets, mean SSF ($P < 10^{-17}$) and the percentage of loins with SSF > 25 kg ($P < 10^{-6}$) were lower for loins predicted tender than loins not predicted tender. Moreover, when this regression equation was validated independently, loins classified as predicted tender had a lower ($P < 10^{-13}$) SSF mean and a lower ($P < 0.001$) percentage of loins with SSF > 25 kg than loins classified as not predicted tender. This technology could facilitate more effective marketing of pork loins and likely will provide pork industry professionals with data on the source of product quality differences.

Introduction: An overview of the researchable question and its importance to producers.

Export markets place strong demand on pork loins that have dark lean color and a high level of marbling. Large-scale packing plants frequently segregate product based on subjective assessment of quality to satisfy the demands of the export markets. But, subjective assessment is prone to errors.

Therefore, there is strong interest in development of practical objective tools for grading of boneless loins.

To ensure high eating quality of pork, the industry has relied on "enhancing" the product with a solution of phosphates, salt, and sometimes flavorings. This approach has been relatively successful (Moeller et al.; 2009); however, there are growing indications that the demand for non-enhanced pork products is increasing and would be considered a premium product. Thus, the ability to select pork that is "naturally" tender for use in a non-enhanced product line would increase the marketing opportunities for pork and the profitability of pork production. A system for noninvasive prediction of pork loin tenderness has been developed and tested under some laboratory and commercial conditions (Shackelford et al., 2011).

While extensive research has been conducted on objective methods to predict meat tenderness, few technologies have been tested under field conditions. The work of these investigators to develop and validate a system based on VISNIR is the only such system that we are aware of that has been tested on-line in a pork packing plant (Shackelford et al., 2011). We have stringently investigated the ability of the VBG2000LED beef carcass grading to predict beef tenderness. Success of the VBG2000LED for prediction of beef tenderness suggested that the beef grading camera should be adopted for grading of pork loins. Therefore, this trial was conducted to test the VQG pork loin grading camera, which is similar to the VBG2000LED but uses a much higher resolution imaging system that is technologically more advanced and simpler than the imaging system in the VBG2000LED.

Objectives:

Develop an accurate method to predict/evaluate meat quality traits of pork loins under industrial conditions.

Materials & Methods:

Testing occurred on 7 production days in 6 large-scale commercial packing plants. The commercial packing plants were selected to provide broad representation of the production and processing diversity that exists in the U.S. pork industry. The plants sampled included some with electrical stunning and spray chilling, some with CO_2 stunning and spray chilling, and some with CO_2 stunning and blast-chilling. During routine loin boning and trimming at each plant (i.e., ~ 22 h postmortem), loins (n = 1,400; 7 days × 200/day) were selected for inclusion in the project and identified with a sequentially-numbered brad inserted into the multifidus dorsi near the posterior end of the loin. At or near the end of the loin boning and trimming line, each test loin was evaluated with the VQG pork loin grading camera. Most test loins were strap-off loins (similar to 414 Pork Loin, Canadian Back but with a 3 mm fat thickness specification). But, 22% of test loins were strap-on loins (similar to 414 Pork Loin, Canadian Back but with up to 25 mm of tail (strap) remaining on the belly side and a 6 mm fat thickness specification). While it was not ideal to sample loins trimmed to different specifications, this was necessary in order to sample ample variation in lean color and marbling, because loins with dark lean color and high levels of marbling were often fabricated as strap-on loins and loins with pale lean color or low levels of marbling were usually fabricated as strap-off loins (Figure 1).

Figure 1. VQG raw images of boneless pork loins. The left image is of a strap-on loin and the right image was a strap-off loin. These two loins were consecutively sampled loins on the same loin trimming line. The loin on the right was imaged (i.e., boned and trimmed) 15 s after the loin on the left. The bottom of each image is towards the posterior end of the loins. These loins are from the right side of carcasses.

The VQG is a manually operated system that is designed to image a 19-cm-long segment of the ventral side of the boneless loin. The imaged area is 19 cm X 15.5 cm. So, a typical image contains a 19-cm-long segment of the ventral side of the boneless loin as well as conveyor belt on either side of the loin. Typically, loins are oriented on loin trimming conveyors with the length of the loin perpendicular to the length of the conveyor and typically loins are consistently oriented with the posterior end of all loins towards the same side of the conveyor. The VQG operator was positioned on the side of conveyors that the posterior end of loins were oriented towards such that the operator imaged loins from each loin's posterior end (Figure 2).

Figure 2. VQG operation on two different loin boning lines. In both cases, the operator is on the same side of the conveyor as the posterior end of the loins are oriented toward. Movies are available at: http://www.eplusv.de/files/USMARC/VQG Movie Trimmed strap-off loins.mp4 and http://www.eplusv.de/files/USMARC/On-line Pre-Trim VQG.MOV

Within 30 s of when each loin was imaged with VQG, 1) objective color was assessed for two locations on the exposed longissimus on the ventral side of the boneless loin using a Hunter Miniscan

XE Plus colorimeter (HunterLab, Reston, VA) with a 25-mm port, D65 illuminant and a 10° observer and 2) subjective color, firmness, and marbling (NPPC, 1999) were evaluated on the exposed longissimus on the ventral side of the boneless loin. Then, using a portable pH meter equipped with a stab electrode, longissimus pH was determined near both the posterior and anterior ends of the loin. Boneless loins were vacuum packaged, boxed, and transported (-2.8°C) to USMARC.

All loins arrived at USMARC within 4 to 10 h of deboning and were immediately refrigerated (1.5°C), unboxed, and placed on solid shelf carts with a single layer of vacuum-packaged boneless loins on each shelf. Vacuum-packaged boneless loins were weighed for subsequent determination of purge loss. All loins were aged dorsal side (fat side) down. At 14 d postmortem, loins were unpackaged, allowed to drip for 5 min, and weighed for determination of purge loss.

Following determination of purge loss, loins were prepared for slicing with a Grasselli NSL 400 portion meat slicer. The posterior end of the loin (~4 cm-long) was removed by a straight cut perpendicular to the length of the loin at a point 5 cm (2 inch) posterior to the anterior tip of gluteus accessorius. The anterior end of the loin was removed by a second cut made 396 mm anterior to the first cut leaving a 396-mm-long center-cut loin section that would fit into the width of the Grasselli NSL 400 portion meat slicer. If present, the strap was removed so that all center-cut loin sections were strap-off before slicing. This approach, maximized yield of chops with the highest proportion of their mass/cross-sectional area comprised of longissimus and excluded chops with a high proportion of their mass/cross-sectional area comprised of other muscles (spinalis dorsi, multifidus dorsi, gluteus medius, gluteus accessorius). Additionally, this approach standardized anatomical location of chop assignment across loins.

The slicing process resulted in 13 chops (28 mm thick) and two end slices (14 mm thick). The end slice from the anterior end was vacuum-packaged, frozen (-20°C) and held for DNA repository. The longissimus from the end slice from the posterior end was trimmed free of other muscles, subcutaneous and intermuscular fat, and epimysium, and diced, snap frozen, and stored (-85°C) for potential analyses.

Chops 5 and 6, which correspond approximately to the 11th rib region of the loin, were used for determination of slice shear force. Immediately after chops were cut and tagged, chops were weighed (initial weight for cooking loss determination) and the time stamp was logged with the scale software. The time stamp was used in subsequent activities to standardize bloom time. The following day (15 d postmortem), chops were cooked, weighed to determine cooking loss, and sampled for slice shear force. Slice shear force was determined for each chop and the mean of those two values was used for all analyses.

Subjective color, firmness, and marbling scores, objective color (Hunter Lab D65/10°) and pH were determined for the posterior face of both chops 3 and 10 and averaged for a composite value for each loin. To insure consistent conditions for evaluation of color, the posterior face of the chops was bloomed (exposed to air) for 3 h before evaluation. The posterior face of Chop 3 was approximately 190 mm from the anterior end of the loin. The posterior face of Chop 10 was approximately 140 mm from the posterior end of the loin. That is, these two locations represented the anterior half and the posterior half of the loin, respectively. For determination of intramuscular fat percentage (IMF), the longissimus of chops 3 and 10 was trimmed free of fat, epimysium, and other muscles, and homogenized and sampled to determine ether-extractable IMF.

Statistics. One-half of the loins were assigned to a calibration (n = 700) data set, which was used to develop regression equations, and one-half of the loins were assigned to a prediction (n = 700) data set, which was used to validate the regression equations. Specifically, odd and even numbered loins were assigned to the calibration and prediction data sets, respectively. Numerous response variables were measured in this study. It would not serve the pork industry any benefit to have a separate regression equation for each response variable. Rather regression equations were developed for a single response variable for each group of related traits. For example, for lean color a regression equation was developed to predict Hunter D65 L* measured on the ventral side of the boneless pork loin at the time of cutting (1 day postmortem). Results of that regression equation were compared to observed objective and subjective color measurements taken on the ventral side of the boneless pork loin at the time of cutting (1 day postmortem) and measurements taken on bloomed chops at 14 d postmortem for the calibration and prediction data sets. Regression analysis was conducted for slice shear force, Hunter L*, IMF, and cooking loss. For each of the dependent variables, the pool of independent variables from the image analysis system was first reduced from 67,186 to 3,000 variables using the PROC CORR statement of SAS with options (rank noprob nosimple BEST=3000). Then, forward stepwise regression was conducted using the PROC STEPWISE procedure of SAS with SLENTRY = 0.05. This narrowed the pool of independent variables from 3,000 to 25, 12, and 29 for L*, IMF, and cooking loss, respectively; but, some variables in those equations were not significant ($P > 0.05$). Backward stepwise (PROC STEPWISE with SLSTAY = 0.0001) was conducted using those variables. The resulting regression equations had 17 (SSF), 5 (Hunter L*), 14 (IMF), and 7 (cooking loss) independent variables, each of which was highly significant ($P < 0.0001$). Those regression equations were used to predict related traits in both the calibration and prediction data sets.

Validation. As a part of NPB #14-221 and to facilitate development of this technology, VQG images and data were collected on the boneless loin from the left side of pigs (n = 7,106) from 8 commercial finishing barns. Materials and Methods were very similar to those described above except that chop cutting occurred at 20 d postmortem, bloom time for chops was 2 h, and slice shear force was determined at 21 d postmortem. When appropriate, that data was used to independently validate equations developed above.

Results:

Assessment of lean color. Noninvasive assessment of loin muscle lean color made with the VQG immediately following loin boning and trimming was strongly correlated to objective and subjective color measurements taken on the ventral side of the boneless pork loin at the time of cutting (1 d postmortem) and measurements taken on bloomed chops at 14 d postmortem (Table 1). The equation, which was developed to predict Hunter colorimeter L* with the calibration data set was effective for the prediction data set suggesting that this equation is robust. For the prediction data set, the VQG camera predictions of loin L* were negatively correlated with subjective color scores of the loin at 1 d postmortem ($r = -0.55$) and bloomed chops at 14 d postmortem ($r = -0.50$). A positive correlation occurred between the VQG camera predictions of loin color and chop L* ($r = 0.78$) for the prediction data set.

Assessment of IMF. VQG predicted IMF was correlated with observed IMF, observed marbling score taken on the ventral side of the boneless pork loin at the time of cutting (1 day postmortem) and observed marbling score taken on bloomed chops at 14 d postmortem for the calibration and prediction data sets and when validated using loins evaluated as a part of NPB #14-221 (Table 2).

Prediction of water-holding capacity. For water-holding capacity, a regression model was developed to predict cooking loss at 15 d postmortem. For the calibration and prediction data sets, predicted cooking loss was positively correlated with cooking loss and purge loss and negatively correlated with pH at 1 and 14 d postmortem (Table 3).

Prediction of tenderness. For tenderness, a regression model was developed to predict slice shear force (SSF) at 15 d postmortem. For the calibration and prediction data sets, mean SSF and the percentage of loins with SSF > 25 kg were lower, for loins predicted tender than loins not predicted tender (Figure 3). Moreover, when this regression equation was validated independently against images and data collected as a part of NPB #14-221, loins classified as predicted tender had a lower SSF mean and a lower percentage of loins with SSF > 25 kg than loins classified as not predicted tender.

Table 1. Correlation of VQG predicted color (Hunter D65 L*) with observed objective and subjective color measurements taken on the ventral side of the boneless pork loin at the time of cutting (1 day postmortem) and measurements taken on bloomed chops at 14 d postmortem for the calibration (n = 700) and prediction (n = 700) data sets.

Measurement	Calibration data set (n = 700)	Prediction data set (n = 700)
Loin L*	0.92	0.90
Loin a*	-0.24	-0.25
Loin b*	0.77	0.66
Chops L*	0.77	0.78
Chops a*	-0.20	-0.19
Chops b*	0.44	0.41
Chops L* Anterior	0.72	0.73
Chops a* Anterior	-0.21	-0.21
Chops b* Anterior	0.40	0.37
Chops L* Posterior	0.71	0.72
Chops a* Posterior	-0.15	-0.14
Chops b* Posterior	0.41	0.39
Loin Color	-0.54	-0.55
Chops Color	-0.46	-0.50
Chops Color Anterior	-0.43	-0.49
Chops Color Posterior	-0.43	-0.46

Table 2. Correlation of VQG predicted intramuscular fat (IMF) percentage with observed IMF, observed marbling score taken on the ventral side of the boneless pork loin at the time of cutting (1 day postmortem) and observed marbling score taken on bloomed chops at 14 d postmortem for the calibration (n = 700) and prediction (n = 700) data sets and when validated using loins evaluated as a part of NPB #14-221.

Measurement	Calibration data set	Prediction data set	Validation data set (NPB #14-221)
IMF	0.78	0.71	0.78 (n = 352)
Marbling score of ventral side of loin at time of boning and trimming (1 d postmortem)	0.65	0.63	0.68 (n = 7,106)
Marbling score of chops at 14 d postmortem after 3 h bloom	0.69	0.64	
Marbling score of anterior chops at 14 d postmortem after 3 h bloom	0.67	0.62	
Marbling score of posterior chops at 14 d postmortem after 3 h bloom	0.65	0.62	0.55 (n = 788)

Table 3. Correlation of VQG predicted cooking loss with observed cooking loss, purge loss, and pH for the calibration (n = 700) and prediction (n = 700) data sets.

Measurement	Calibration data set	Prediction data set
Cooking loss, %	0.62	0.50
Purge loss of vacuum-packaged loin during aging (1 to 14 d postmortem), %	0.44	0.38
Loin pH at 1 d postmortem	-0.51	-0.47
Chop pH at 14 d postmortem	-0.37	-0.36

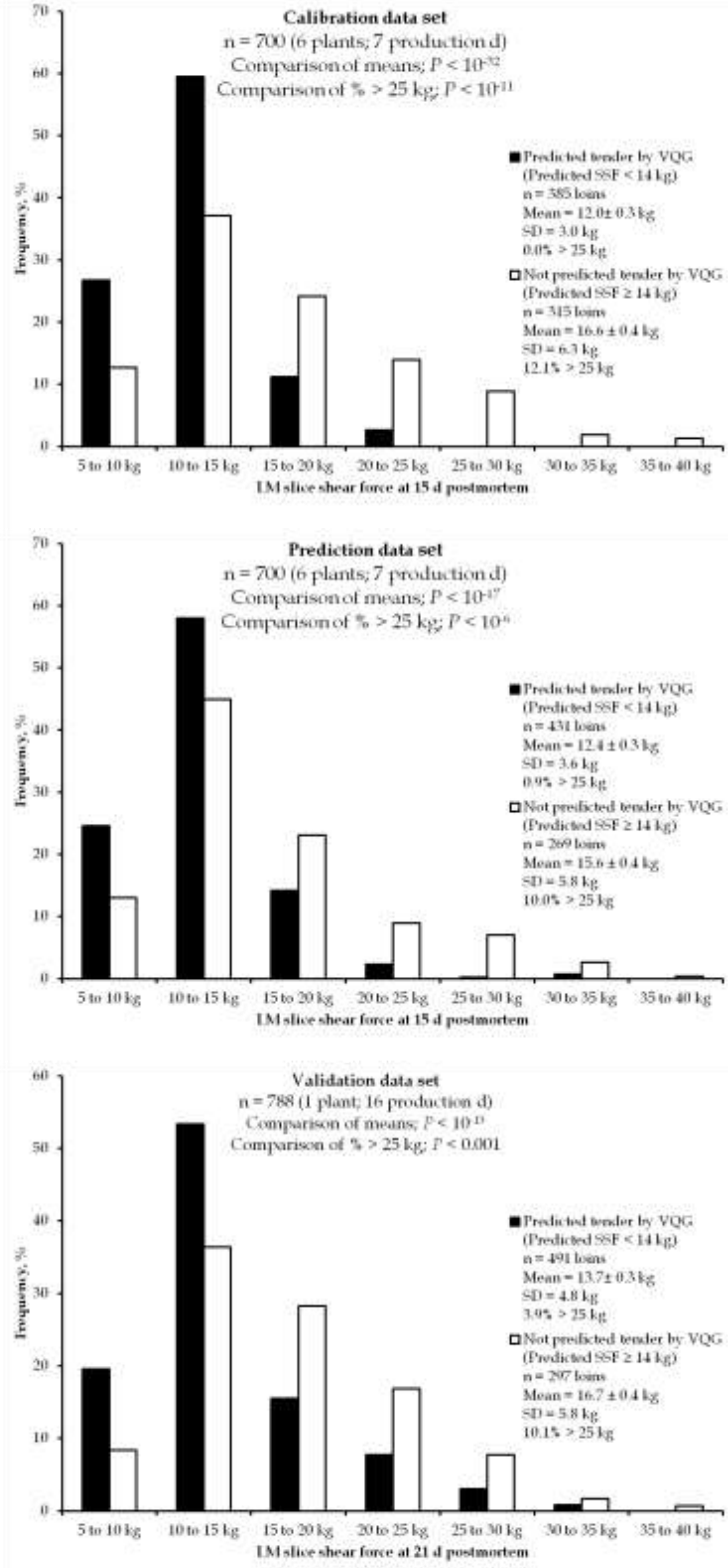


Figure 3. Effect of sorting carcasses into predicted tenderness classes using the VQG pork loin grading camera on LM slice shear force. Loins with VQG-predicted SSF < 14 kg were classified as predicted tender by VQG. The top panel shows the calibration data set, which was used to develop the model. The middle panel shows the prediction data set, which was used to evaluate the model. The bottom panel shows indepent validation of system using loins evluated as a part of NPB #14-221.

Discussion:

This technology provides the pork industry with a tool to evaluate meat quality characteristics of boneless loins at commercial processing speeds. This could be used to determine which loins qualify for a specific brand or to facilitate real-time decision making in regards to how each loin should be trimmed to meet the needs of diverse markets. The software has been designed with flexible classification settings (Figure 4) to allow industry professionals the ability to easily tailor the system to maximize value. For tenderness, the system is set to make a two level classification. The data indicate that the maximum predicted SSF for loins classified as tender should not exceed 14 kg. However, some operators may want to lower that threshold to identify loins with a very high probability of being consistently tender. As shown in Figure 4, values can be set to assign loins to the proposed NPB grading system. Figure 5 shows the VQG display for three loins with differing characteristics.

Interest in the VQG has been strong. Trial installations will occur at a packing plant owned by one company in March and at a packing plant owned by another company in April. Yet, another company has asked for a permanent installation in the coming months. We have collaborated with several companies and the University of Illinois to collect VQG data as part of research trials. Also, we have consulted with one swine genetics company regarding how they might use this technology to aid selection for improved meat quality.

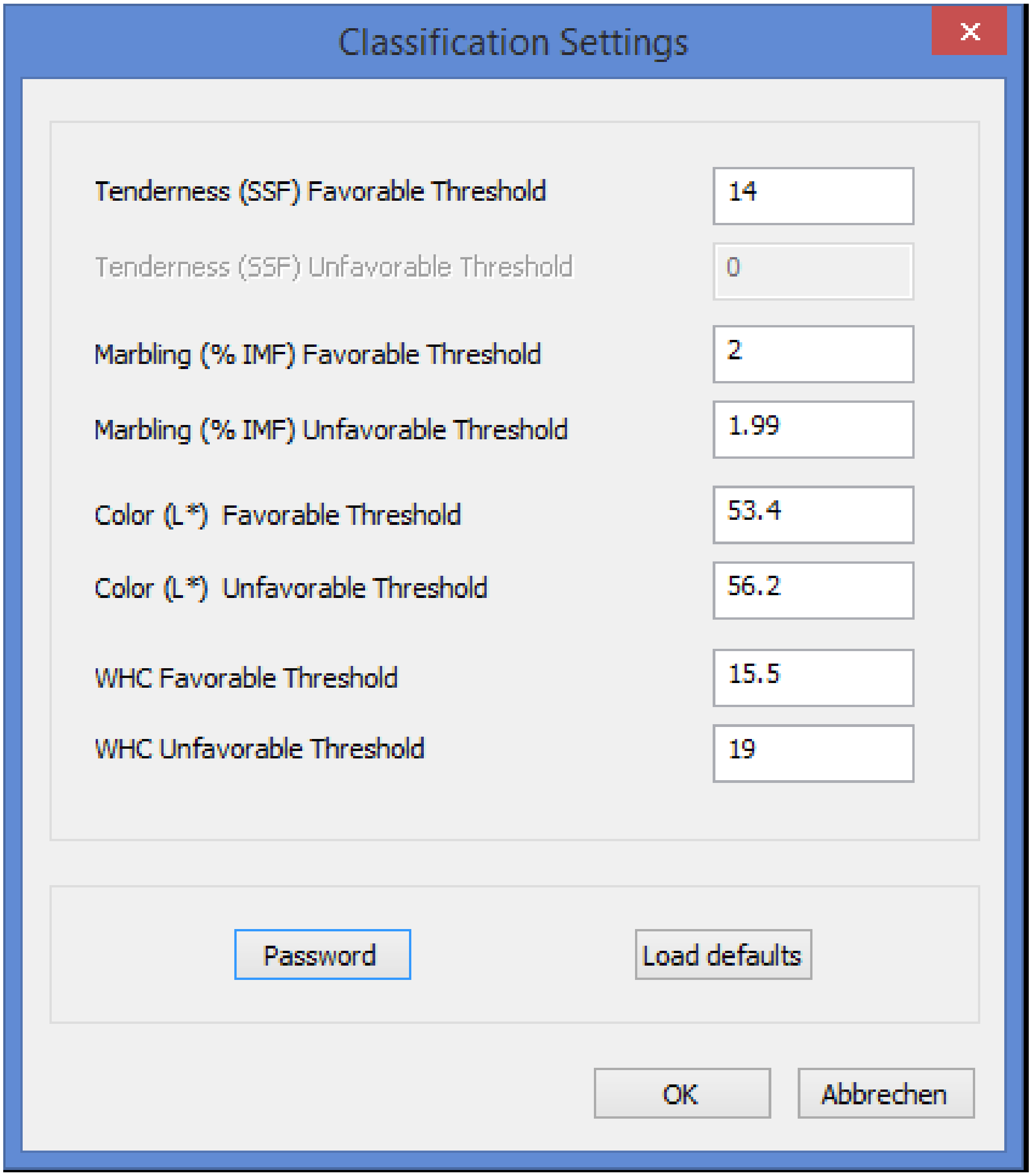


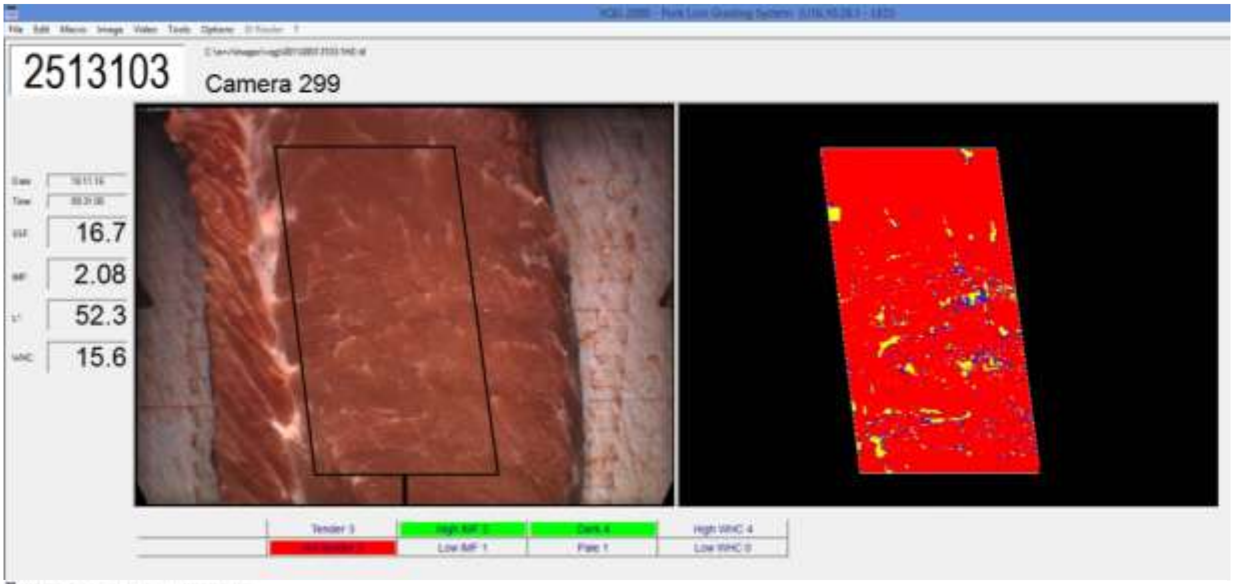
Figure 4. VQG classification settings.

Loins with predicted SSF < the Tenderness (SSF) Favorable Threshold are classified as “Tender”. Otherwise loins are classified as “Not tender”.

Loins with predicted IMF > the marbling (%IMF) favorable threshold are classified as “High IMF”. Loins with predicted IMF < the marbling (%IMF) unfavorable threshold are classified as “Low IMF”. Loins with IMF between the favorable and unfavorable thresholds are classified as “Normal IMF”. In this case, the favorable and unfavorable thresholds are identical to create a two-level classification system which is align to the proposed NPB grading system.

Loins with predicted L* < the Color (L*) favorable threshold are classified as “Dark”. Loins with predicted L* > the Color (L*) unfavorable threshold are classified as “Pale”. Loins with L* between the favorable and unfavorable thresholds are classified as “Normal color”.

Loins with High IMF and Dark lean color would qualify for the NPB High Quality grade. Loins with High IMF and Normal lean color would qualify for the NPB Medium Quality grade.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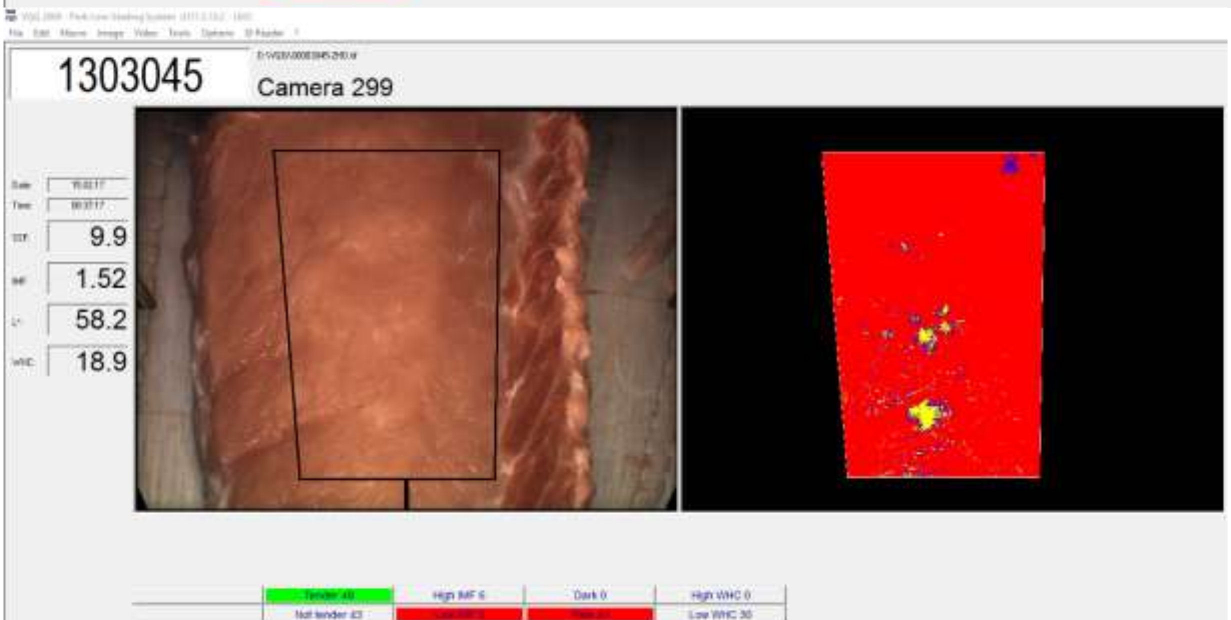
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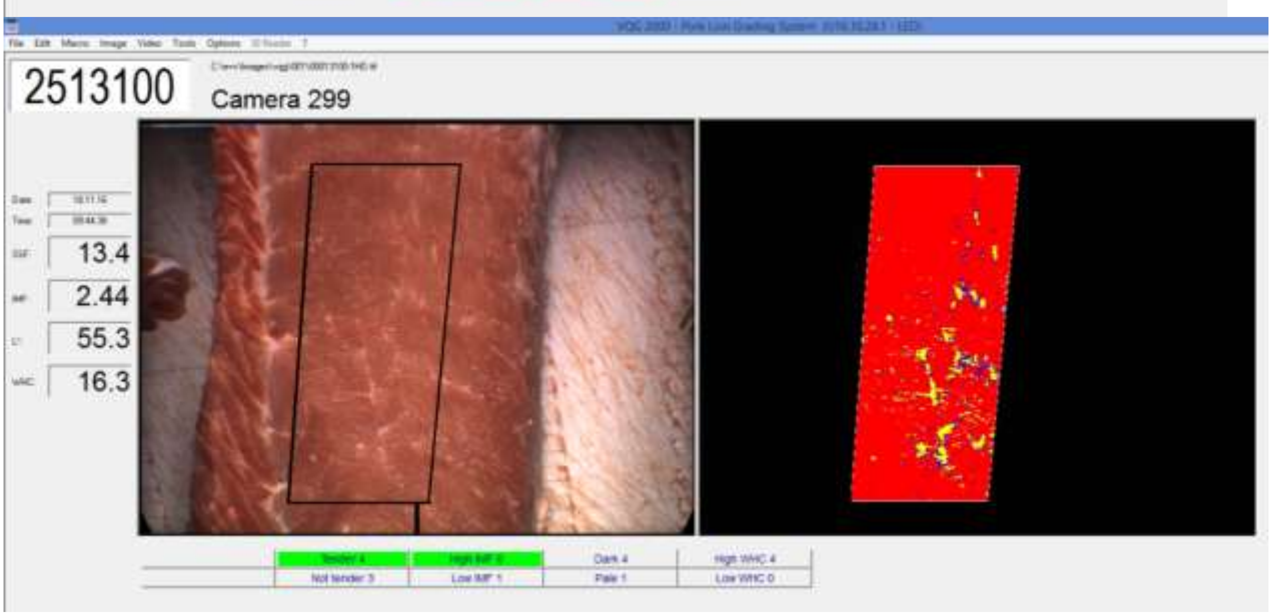
2513100
Camera 299
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2.44
55.3
16.3

Figure 5. VQG display. The top pane shows a loin that had a predicted SSF value of 16.7 kg, predicted IMF of 2.08%, predicted L* of 52.3, and predicted cooking loss of 15.6%. That loin was classified as "Not tender", "High IMF", "Dark", and "Normal water-holding capacity (WHC)". The middle pane shows a loin that had a predicted SSF value of 9.9 kg, predicted IMF of 1.52%, predicted L* of 58.2 and predicted cooking loss of 18.9%. That loin was classified as "Tender", "Low IMF", "Pale", and "Normal WHC". The bottom pane shows a loin that had a predicted SSF value of 13.4 kg, predicted IMF of 2.44%, predicted L* of 55.3, and predicted cooking loss of 16.3%. That loin was classified as "Tender", "High IMF", "Normal color", and "Normal WHC".

Literature Cited

Moeller, S. J., R. K. Miller, H. Zerby, K. Edwards, K. Logan, and M. Boggess. 2009. Effects of pork loin quality and enhancement on consumer acceptability and cooking characteristics of pork loin chops. Proc. Recip. Meat Conf. 62:4-15.

NPPC. 1999. Pork quality standards. Natl. Pork Prod. Counc. Des Moines, IA.

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.