Colorado State University

Knowledge to Go Places

Final Report

Validation of Regression Equations that Utilize Lamb Vision System (LVS) Output to Predict Lamb Carcass Fabrication Yields [a]

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Executive Summary

This study was performed to: (a) Validate prediction equations developed by Brady et al. (2002), and scientifically verify their appropriateness for use in commercial lamb carcass pricing systems. (b) Test and implement a second component of the dual-component Lamb Vision System (LVS) system; i.e., a cold-carcass video imaging system that accurately and repeatably measures lamb carcass longissimus muscle area as well as fat percentage in the 12th /13th rib interface. Lamb carcasses (N = 149) were selected by Colorado State University (CSU) personnel, scanned using the LVS system, and chilled. Chilled carcasses were assigned On-Line USDA Yield Grades (at chain speeds, by regular plant graders) and Expert USDA Yield Grades (by grading supervisors, with unlimited time and access to the carcasses); grade factors and/or the grade were recorded for each carcass. Carcasses were fabricated into bone-in subprimal/primal cuts. Yield data for an individual carcass was included in the study only if the aggregate sum of weights for all parts of that carcass totaled at least 98% of its initial chilled carcass weight. The following yields were calculated for each carcass: (a) "saleable meat yield", which refers to bone-in subprimal/primal cuts plus lean trim from the leg, loin, rack and shoulder, along with thin cuts, as a percentage of chilled carcass weight, (b) "subprimal yield", which refers to the bone-in cuts from the leg, loin, rack, and shoulder as a percentage of chilled carcass weight, (c) "fat yield", which refers to the trimmable fat generated from the production of subprimal/primal cuts as a percentage of chilled carcass weight, (d) "lean trim yield", which refers to lean trim generated from the production of subprimal/primal cuts as a percentage of chilled carcass weight, and (e) "bone yield", which refers to the weight of bones removed during production of subprimal/primal cuts as a percentage of chilled carcass weight.

On-Line (whole-number) USDA Yield Grades accounted for 58.9%, 58.5% and 64.5% of the observed variability in saleable meat yields, subprimal, and fat yields, respectively. Expert (whole-number) USDA Yield Grades explained 59,0%, 58.6% and 64.9% of the observed variability in saleable meat yields, subprimal yields, and fat yields, respectively. Expert (nearest-tenth) USDA Yield Grades accounted for 60%, 59.8% and 67.3% of the observed variability in saleable meat yields, subprimal yields and fat yields, respectively.

The best LVS prediction equation, developed in this trial using LVS output and hot carcass weight as independent variables, explained 67.6 % of the variation in saleable meat yields, which was a 9 percentage point improvement compared to the accuracy of On-Line (whole-number) USDA Yield Grades, a 7 percentage point improvement compared to Expert (nearest-tenth) USDA Yield Grades, and an 8 percentage point improvement compared to Expert (whole-number) USDA Yield Grades. The LVS prediction equation accounted for 61.9% of the subprimal yields, which was an improvement of 3 percentage points in comparison to the proportion of the variation in subprimal yields explained by On-Line (whole-number) USDA Yield Grades, a 3 percentage point improvement compared to that proportion of variation subprimal yields explained by Expert (nearest-tenth) USDA Yield Grades, and a 3 percentage point improvement compared to Expert (whole-number) USDA Yield Grades. In addition, the Lamb Vision System prediction equation explained 73.8% of the variation in bone-in, fat yields, which was a 9 percentage point improvement over the predictive ability of On-Line (whole-number) USDA Yield Grades, a 6 percentage point improvement over the predictive ability of Expert (nearest-tenth) USDA Yield Grades, and a 9 percentage point improvement compared to Expert (whole-number) USDA Yield Grades.

Using the best-fit regression equation developed by Brady et al. (2002) explained 55.8% of the variation in saleable meat yield, 45.9% for subprimal yield and 61.2% of the variability in fat yield, which were comparable to the amounts of variability explained by the both On-Line and Expert USDA Yield Grades. Applying the newly developed best-fit regression equation to the data collected from lamb carcasses by Brady et al. (2002) explained 59.4% of the variability of saleable meat yield, 54.8% and 75.4% of the variation in subprimal and fat yields, respectively.

The LVS output, along with hot carcass weight, also was used to predict the weight of each primal cut from each carcass. Lamb Vision System prediction equations explained 88%, 78%, 68%, and 83% of the variation in weights of bone-in shoulders, racks, loins, and legs, respectively. Addition of Longissimus Muscle Area (LMA) and overall percent fat in the $12^{th}/13^{th}$ rib interface obtained with the second component of the dual component system (i.e., the cold carcass system), improved predictive accuracy of the equations; the combined output equations explained 71.9% and 65.6% of the variability in saleable meat yield and subprimal yield, respectively. Accuracy and repeatability of the measurements of longissimus muscle area (LMA) made with the cold-carcass system also were assessed; results suggested that use of LVS results in accurate and repeatable measurements of LMA.

Use of the LVS to predict bone-in cut yields of lamb carcasses improved accuracy and precision as compared to On-Line (whole-number), Expert (whole-number), or Expert (nearest-tenth), USDA Yield Grades. When used alone, or in combination with the output from the cold carcass system, LVS output enhanced On-Line estimation of boneless cut yields from lamb carcasses. In addition, accuracy of LVS for predicting weight of wholesale cuts suggests that this system could be used as an objective means for pricing carcasses in a value-based marketing system.

Introduction

The need in the lamb industry for an objective and accurate method of predicting red meat yield, as well as the true value of lamb carcasses, has long been acknowledged. Brady et al. (2002) studied the ability of the lamb vision system (LVS: Research Management Systems USA, Fort Collins, CO) to predict fabrication yields of lamb carcasses; results of that study demonstrated the ability of LVS to predict fabrication yields and, thus true monetary values of lamb carcasses, more accurately than does the current system based on weight and USDA Yield Grades.

Purcell (1995) and Ward (1998) reported that slaughter lambs are priced according to dressing percentage and hot carcass weight, while cutability differences are basically ignored. In order for the lamb industry to produce a leaner end-product, there remains a need to develop an objective, accurate method to predict lean meat yield that will also serve as an objective method for assigning monetary values to lamb carcasses.

The U.S. beef industry has explored the use of carcass assessment instrumentation, primarily by evaluating video image analysis (VIA) equipment in an effort to improve accuracy in predicting carcass cutability, and thus carcass value. Cannell et al. (1999; 2002) determined that VIASCAN™ and Computer Vision System technology, respectively, could predict fabrication yields more accurately than did Yield Grades assigned by USDA line graders. In a subsequent study, Steiner et al. (2000) employed both instrumentation and On-Line grader estimates in an On-Line augmentation system to predict beef carcass yield. They reported that augmentation of the application of Yield Grades by USDA line graders with VIA, in real time, could significantly increase the accuracy with which subprimal yields are predicted (Steiner et al., 2000). In another study, Steiner et al (2003) reported that video image analysis instrumentation can be used to

assess longissimus muscle area of beef carcasses with high levels of accuracy and repeatability.

Because of the intention of Mountain States Lamb Cooperative to utilize LVS for value-determining purposes, it is necessary to validate the prediction equations developed by Brady et al. (2002). Therefore, the objectives of this study were to scientifically verify the appropriateness of the use of Lamb Vision System (LVS) for use in commercial lamb carcass pricing systems, and to test and implement a second component of the dual-component LVS system (i.e., a second cold-carcass video imaging system that accurately and repeatably measures lamb carcass longissimus muscle area).

Experimental Procedures

Carcass selection and hot-carcass imaging

Lamb carcasses (n = 149) were selected by Colorado State University personnel at a commercial packing plant after harvest, but before entering the chilling coolers. During each of the five selection days of the study, carcasses were selected to fit an experimental design on the basis of sex class (ewe and wether), hot carcass weight (light = $\leq$ 29.48 kg, medium = 29.94 kg to 34.02 kg, and heavy = $\geq$ 34.47 kg) and USDA Yield Grades (1 through 5; USDA, 1992), and within USDA Yield Grades, an approximately equal number of carcasses were selected to fill two muscling subclasses (light or heavy), included to ensure that cutability differences were not due to fatness differences alone. Lamb carcasses selected for inclusion in this study reflected the extreme range of variation in carcass traits experienced at the commercial facility each week. Such variability ensured that the lamb vision system (LVS; Research Management Systems USA, Fort Collins, CO) would be tested for accurate prediction of carcass cutability across the extreme range of differences

in composition encountered in the present U.S. lamb population. The experimental design for this study and the carcass selection grid are outlined in Table 1.

Immediately following selection, but before carcass chilling, carcasses were scanned using the LVS, and LVS images, hot carcass weight (HCW), and carcass identification numbers were recorded.

The carcass assessment unit of LVS consists of a stationary camera with built-in standardized lighting, a processor, and a monitor housed in a stainless steel cabinet which contains a computer processor. Following image acquisition, LVS software operates by: (1) recording an image of a background, (2) recording an image of the carcass, and (3) subtracting the carcass image from the background image to provide a defined image of the carcass. In addition, LVS software recognizes all anatomical points that are needed to make a series of total carcass measurements. Measurements made by the LVS software include, but are not limited to, carcass length, groin to right leg length, groin to left leg length, distance from groin to the end of the shank, red color score for shoulder, blue color score for shoulder, red color score for loin, blue color score for loin, distance between the two legs, groin area, carcass area measurements, total carcass width measurements, leg area measurements, leg width measurements, and groin angle measurements. These measurements were utilized as system output variables related to shape and size of the carcass, degree of muscularity and relative proportions of fat and lean trim.

During each selection day of the study, an adequate number of carcasses were selected for scanning to ensure that the correct number of carcasses would be available to fill the experimental design. Carcasses with slaughter defects (carcass defects that would normally prevent assignment of USDA Yield Grades) were not selected for the study. The test carcasses were then moved to the chilling cooler (-3°C to 1°C) for 24 h of spray-

chilling, except when it was not possible to perform fabrication of all the carcasses in the next day, which occurred in two days of the study; on those two days, carcasses were chilled for 48 h.

Carcass grading and Cold-carcass imaging

Following chilling, all carcasses were circulated past the grading stand, where, at normal chain-speeds of approximately 480 carcasses/h, a USDA grader (employee of USDA-AMS) assessed and stamped a USDA Quality Grade and a USDA Yield Grade (USDA, 1992) on the exterior of each carcass. After receiving a On-Line USDA grade, the selected carcasses were sorted to a static holding rail.

An "Expert" USDA grader (a field supervisor of USDA-AMS) then assigned and recorded USDA quality grade and Yield Grades factors ("Gold Standard" factors), as well as a final USDA quality grade and a final USDA Yield Grades for each carcass, with the aid of a grading probe and in whatever period of time was necessary to maximize accuracy and precision of grade or grade factor assignments. These "Gold Standard" factors and Expert (whole number) USDA Yield Grades were used to determine which carcasses fit the project design.

Each lamb carcass was then ribbed to expose the ribeye (12th and 13th rib interface of the *longissimus* muscle) and, following carcass grading but before fabrication, each carcass was scanned using the cold-carcass video imaging system in a manner such that three "triple trigger" and three "placement" (Steiner, 2003) images were collected and recorded for each carcass.

The cold-carcass component of the LVS consists of unit that records a digital image of the exposed surface of the interface of the $12^{th}/13^{th}$ ribs; that image is then processed by the software and the *longissimus* muscle area is traced and measured; fat thickness also is

measured at three different points and percent overall fat is computed. The longissimus muscle area (LMA) also was measured using a grid by Colorado State University personnel, before fabrication.

Carcass fabrication

All cutting and trimming steps during fabrication were performed by experienced packing plant meat-cutters, supervised by Colorado State University personnel.

The foresaddle and hindsaddle of each carcass were separated between the 12th and 13th ribs and weighed; the sum of the two saddles was used to determine chilled carcass weight. The saddles were split and each forequarter and each hindquarter of all carcasses were then further divided to generate shoulder, rack, loin, and leg primal cuts. Each primal cut was weighed so that primal weights could be combined to allow carcass weight to be reconciled for each unit. Primal cut weights were reconciled by assuring that the combined weights of all bone-in cuts lean trim, fat trim, and bone totaled 98% of initial primal weight.

Subprimal/primal cuts generated from fabrication were closely-trimmed of external fat (0.64 cm), and all subsequent parts were weighed and recorded. Bone-in subprimal cuts (USDA, 1996; these were not certified by USDA but closely approximate the appropriate IMPS description, when applicable) generated included: square-cut shoulder (IMPS 207); neck; foreshank (IMPS 210); ribs, breast bones off (IMPS 209A); split and chined rack (IMPS 204A); loin short-cut, trimmed, 2.54 cm tail (IMPS 232A); leg (IMPS 233D); and hindshank (IMPS 233G).

All parts of each cut were retained and weighed, and the aggregate weight of all parts was calculated for each primal cut. Total aggregated cut weights from each carcass had to sum to at least 98% of the initial chilled carcass weight, or data from that carcass

were removed from the study. Data from eight carcasses were not included in results of this study; their identification numbers as well as the reasons for their not being included in the analysis are shown in table 2.

Fabrication yields for bone-in cuts were calculated as a percentage of the weight of the bone-in chilled carcass weight. The following yields were calculated for each carcass: "saleable meat yield" was the sum of weights of bone-in subprimal/primal cuts, plus lean trimmings from the leg, loin, rack, shoulder, and thin cuts, calculated as a percentage of chilled side weight; "subprimal yield" was the sum of weights of bone-in cuts from the leg, loin, rack, and shoulder calculated as a percentage of chilled side weight; and "fat yield" was the sum of trimmable fat weights generated from production of subprimal/primal cuts and calculated as a percentage of chilled side weight.

Statistical Analysis

All statistical analyses, including descriptive statistics, correlation, and regression, were performed using the PROC GLM and PROC REG procedures of SAS (SAS Inst. Inc., Cary, NC). Multiple regression analysis was used to regress dependent carcass yield percentages on the independent variables of LVS output and hot carcass weight, in an effort to develop a model for the prediction of red meat yield. Regression equations for the prediction of weight of subprimal cuts from each primal were developed using linear methods that were allowed to include LVS output variables and hot carcass weight. Stepwise, forward, and backward selection methods were used to determine which independent variables were common and significant ($\alpha = 0.05$) for each method of selection. Variables not selected by any of the three selection methods were excluded from the regression analysis and the three selection methods were performed once more to build

models for the various dependent carcass yield percentages. The root mean square error (RMSE) and predicted residual sum of squares (PRESS) statistics were computed to assess precision of red meat yield prediction models. Best-Fit models were selected based on simplicity, R^2 value, PRESS value, and the RMSE value.

Dependent carcass yield percentages also were regressed on USDA On-Line and Expert Yield Grades, with the USDA Yield Grade serving as the sole independent variable in the model. Root mean square error and PRESS statistics were calculated for each regression equation to determine precision of the red meat yield model predictions. These regression equations were compared to the best-fit equations developed using LVS output and hot carcass weight as independent variables.

Results and Discussion

Descriptive statistics for the 149 carcasses in the sample population are presented in Table 3. Inasmuch as the sample population was selected to represent an extreme range of variability in carcass traits present in a commercial facility, the large standard deviations for hot carcass weight, fat thickness, and USDA Yield Grades were due to this intentional selection for carcass variation.

Regression equations developed by Brady et al. (2002) were applied to carcasses included in the present study data-set, exactly the same variables were used but the coefficients were allowed to change. Coefficients were allowed to differ from Brady et al. (2002) due to hardware and software adjustments incorporated into the LVS between the two studies; these adjustments were necessary in order to improve and update the LVS.

Equations developed by Brady et al. (2002) explained 55.8%, 45.9% and 61.6% of the observed variability in saleable meat yield, subprimal and fat yield yields, respectively.

Values for R^2, RMSE, and PRESS statistics for these regression equations are presented in Table 4.

On-Line (whole-number) USDA Yield Grades, Expert (whole-number) USDA Yield Grades, and Expert (nearest-tenth) USDA Yield Grades were each regressed on carcass yields, and the values for R^2, RMSE, and PRESS statistics for the regression equations also are presented in Table 4. Expert (whole-number) USDA Yield Grades explained 59.1%, 58.7%, and 64.9% of the observed variability in saleable meat yields, subprimal yields, fat yields, respectively.

As would be expected, the Expert (nearest-tenth) USDA Yield Grades explained slightly more of the observed variability than did On-Line (whole-number) or Expert (whole-number) USDA Yield Grades, in yields of saleable meat, subprimals and fat, for the carcasses fabricated in this study. Regression equations for Expert (nearest-tenth) USDA Yield Grades were accompanied by lower RMSE and PRESS values than for On-Line or Expert, whole number USDA Yield Grades, suggesting greater precision in estimation of yields for saleable meat, subprimals, and fat.

Regression models to predict weights, rather than percentages, of wholesale, major-primal cuts from lamb carcasses were developed; R^2 and RMSE values for these equations are presented in Table 5. The high accuracy with which these regression models (Table 5) were able to predict weights of wholesale cuts was, in part due to the auto-correlation that existed between hot carcass weights and some wholesale cut weights in regression models. Partial R^2 values for the independent variables in the regression models indicated that a strong relationship existed between HCW and weights of shoulder and rack when fabricated to either the boneless or bone-in style, and between HCW and bone-in weights of leg. Garrett et al. (1992) and Jones et al. (1992) previously reported that hot carcass

weight is highly correlated to carcass yields of fabricated cuts, and thus, is an important factor to be included in lamb carcass cutability prediction models.

To further explore the use of the LVS output and to better explain the variability in shape of the lamb carcass as it changes due to fattening, some new variables were developed using width measurements from the LVS outputs and computing ratios of these widths in certain regions of the carcass that had meaning by being in specific anatomical points of interest. The first new variable created was a ratio between the elbow pocket width (minimum width measured in shoulder and rack) and the body wall width (maximum width measurement in the rack). The other new variable developed to be used in the model was a ratio between the loin width and shoulder width; use of these two variables, along with other LVS output variables improved explanation of observed variation in percentage yields. The best-fit regression equation developed in the present study using the newly computed variables, along with hot carcass weight, explained 67.6%, 61.9% and 73.8% of the observed variability in saleable meat yield, subprimal yield and fat yield, respectively (Table 6), representing a significant improvement over use of USDA Yield Grades in the ability to predict of percentage yields of lamb carcasses.

To verify the validity of this newly developed equation, it was applied to data collected by Brady et al. (2002); comparable results were achieved. Values for R^2, RMSE, and PRESS statistics for the regression equations developed to predict saleable meat yield, subprimal yield and fat yield are presented in Table 6. In addition, the best-fit regression equation developed in the present study was fitted to data collected in this study and data from the earlier study (Brady et al. 2002); differences in the coefficients for the equations were, again, undoubtedly explained by adjustments made to the hardware and software of the LVS between the times of the two trials. The slight difference in results for values for

R^2, RMSE, and PRESS statistics were probably explained by the differences among lamb carcasses in the two populations; the Brady et al. 2002 population was more evenly distributed across all five USDA Yield Grades, while the population of the present study contained disproportionately more carcasses of Yield Grades 2 and 3, which is more nearly representative of the actual consist of U.S. lamb carcasses.

Use of a combination of the outputs of the two dual-component LVS improved predictive accuracy of yield estimation equations. Regression equations developed using a combination of the two outputs plus hot carcass weight explained 71.9% of the variation in saleable meat yield (Table 7). In this model, the overall percent fat measure (obtained with the cold system) explained 52.6% of this variation; the regression equation to predict subprimal yield explained 65.6% of the observed variation when a combination of the two LVS devices were used. The variables used in the models, and the values for R^2, partial R^2, RMSE, and PRESS statistics are presented in Table 7.

The accuracy of the measurements of longissimus muscle area (LMA) were assessed by taking the measurements of each of the three images from the "triple trigger" procedure (Steiner et al. 2003) obtained with the Video Image Analysis (VIA) and regressing them on the measurements collected by Colorado State University personnel using the grid (defined as "actual" LMA). The descriptive statistics for those measurements are presented in Table 8.

Coefficients of determination (R^2) and residual standard deviations (RSD) for CSU-gridded LMA regressed on VIA measured LMA for each of the three images are presented in Table 9. The regression explained 59, 56 and 60% of the variation in the area measured by LVS in images 1, 2, and 3, respectively. The R^2 values could have been higher if variability in the "actual" LMA was controlled by taking more than one measurement and

then averaging them, or if more accurate method had been used to define "actual" LMA (e.g., acetate paper tracing and planimeter measurements; Steiner et al. 2003).

Repeatability of LMA measurements was assessed by calculating the mean absolute differences for LMA using two methods of VIA measurement (Table 10). Mean absolute differences were 0.13 cm^2 and 0.15 cm^2 when the "triple trigger" (three images taken without moving the camera head) and for "three placements" (three images taken removing the camera head and placing it back between each of the images) methods were used. The small mean absolute difference and standard deviation values (Table 10) suggested that LVS is highly repeatable in measuring LMA. Variance components and the percentage of total variance in repeated LMA measures accounted for by independent models for "triple trigger" and "three placements" methods are presented in Table 11. In both methods of measuring LMA using LVS, more than 98% of the total variance in LMA was accounted for by the differences between carcasses (repeatability = >0.98). Results of this study suggested that although there is room for improvement in the accuracy of the measurements by the use of LVS, the repeatability of the measurements was excellent in application; the system has the ability of consistently measuring LMA.

Conclusions

Use of the On-Line Lamb Vision System (LVS) explained a greater proportion of the observed variation in yields of bone-in cuts from carcasses than did Expert (whole-number) USDA Yield Grades, Expert (nearest-tenth) USDA Yield Grades, or On-Line (whole-number) USDA Yield Grades.

Utilizing a combination of output from both of the two dual-component devices of LVS improved the predictive ability of percent yields in lamb carcasses.

In addition, when combined, the outputs of the two dual-component LVS regression equations were typically more precise in predicting yields of bone-in or boneless cuts from carcasses than were equations using Expert (whole-number) USDA Yield Grades, Expert (nearest-tenth) USDA Yield Grades, or On-Line (whole-number) USDA Yield Grades, singularly, as the independent variables.

Results suggested that the cold-carcass system has the ability to accurately and repeatably measure LMA, although further study is recommended to assess, more definitively, the accuracy of the LVS once it is in use in lamb packing plants.

The results of the present study demonstrate that LVS is an important tool for developing a value-based pricing system for lamb carcasses. Such a pricing system is needed in the U. S. lamb industry, in order to encourage the producers to produce leaner lamb.

Table 1. Experimental design: numbers of carcasses included in the study by sex class, weight, and USDA Yield Grades (YG) category.

Expert (whole-number) USDA YG	Wethers (n = 80)[a]			Ewes (n = 69)[a]			Complete population
	Light[b]	Medium[c]	Heavy[d]	Light[b]	Medium[c]	Heavy[d]	
YG1	3	2	2	0	8	1	16
YG2	8	10	6	10	6	0	40
YG3	7	11	15	9	12	12	66
YG4	0	2	10	1	3	4	20
YG5	0	2	2	0	1	2	07
Total	18	27	35	20	30	19	149

[a]Lambs selected were approximately equal in number of light vs. heavy muscled lambs.

[b]Light: $\leq$ 29.48 kg.

[c]Medium: 29.94 kg to 34.02 kg.

[d]Heavy: $\geq$ 34.47 kg.

Table 2: A summary of carcasses removed from the analyses

Selection Date	CSU ID #	Reason
02-19-2003	160	Hot carcass weight < Chilled carcass weight
02-19-2003	178	Hot carcass weight < Chilled carcass weight
02-19-2003	195	Hot carcass weight < Chilled carcass weight
03-03-2003	221	Not fabricated because of Yearling Mutton class
03-05-2003	236	< 98 % Fabricated weight sum
03-05-2003	250	Not fabricated due to an injection-site lesion
03-05-2003	264	Missing the fat trimmings from the leg
03-05-2003	285	Image and measurements not recorded properly

Table 3: Descriptive statistics for USDA Yield Grades factors

Grade factor	**n**	**Mean**	**SD**	**Minimum**	**Maximum**
Hot carcass weight, kg	149	33.36	5.54	23.60	54.39
Chilled carcass weight, kg	149	33.17	5.50	23.69	54.03
Fat thickness, cm	149	0.70	0.23	0.13	1.37
Adjusted fat thickness, cm	149	0.72	0.23	0.13	1.42
Expert Yield Grades, (nearest-tenth)	149	3.23	0.92	1.00	5.90
Expert Yield Grades, (whole-number)	149	2.73	0.98	1.00	5.00
On-Line Yield Grades, (whole-number)	149	2.68	1.01	1.00	5.00

Table 4: Independent variables, R^2, predicted residual sum of squares (PRESS) and root mean square error (RMSE) for best-fit regression equations developed by Brady et al. (2002) to predict percent carcass yields using lamb vision system output plus hot carcass weight, Expert (whole-number) USDA Yield Grades, Expert (nearest-tenth) USDA Yield Grades, and On-Line (whole-number) USDA Yield Grades

Dependent variables	R^2	PRESS	RMSE	Variables in model (partial R^2)[f]
Saleable meat yield, %[a]	0.5581	0.0946	0.0241	HCW (0.1711) CxsLen (0.2866) GrLftLeg (0.0286) LegGap (0.000) TaSum (0.0124) LwSum (0.0235) GrAnSm (0.0082) ShBi (0.0277)
	0.5914	0.0777	0.0227	Expert (whole-number) USDA Yield Grades
	0.6044	0.0754	0.0223	Expert (nearest-tenth) USDA Yield Grades
	0.5890	0.0781	0.0227	On-Line (whole-number) USDA Yield Grades
Subprimal yield, %[b]	0.4588	0.0631	0.0199	HCW (0.1599) CxsLen (0.2283) LegGap (0.0043) ShBi (0.0514) TaSum (0.0059) LwSum (0.0090)
	0.5865	0.0443	0.0171	Expert (whole-number) USDA Yield Grades
	0.5986	0.0430	0.0169	Expert (nearest-tenth) USDA Yield Grades
	0.5854	0.0444	0.0171	On-Line (whole-number) USDA Yield Grades
Fat yield, %[c]	0.6155	0.0991	0.0249	HCW (0.0166) CxsLen (.1098) ShRi (0.0079) TwSum (0.4531) LwSum (0.0002) LaSum (0.0135) GrAnSm (0.0143)
	0.6492	0.0820	0.0233	Expert (whole-number) USDA Yield Grades
	0.6732	0.0767	0.0225	Expert (nearest-tenth) USDA Yield Grades
	0.6494	0.0820	0.0233	On-Line (whole-number) USDA Yield Grades

[a]Saleable meat yield = subprimal cuts and lean trim from the leg, loin, rack, shoulder, and thin cuts as a percentage of chilled side weight.

[b]Subprimal yield = subprimal cuts from the leg, loin, rack, and shoulder as a percentage of chilled side weight.

[c]Fat yield = percentage of chilled side weight of fat from the production of subprimal cuts.

[d]Lean trim yield = percentage of chilled side weight of lean trim from the production of subprimal cuts.

[e]Bone yield = percentage of chilled side weight of bones removed during production of subprimal cuts.

[f]HCW = hot carcass weight, CxsLen = carcass length, GrRtLeg = groin to right leg length, GrLftLeg = groin to left leg length, ShRi = red color score for shoulder (adjusted for intensity), ShBi = blue color score for shoulder (adjusted for intensity), LnRi = red color score for loin (adjusted for intensity), LnBi = blue color score for loin (adjusted for intensity), LegGap = distance between the two legs, GroinA = groin area, TaSum = sum of 20 total carcass area measurements, TwSum = sum of 20 total carcass width measurements, LaSum = sum of five leg area measurements, LwSum = sum of five leg width measurements, GrAngSum = sum of five groin angle measurements.

Table 5. independt variables, R^2, root mean square error (RMSE), and partial R^2 for regression equations using lamb vision system output variables and hot carcass weight (HCW) to predict the weight of wholesale cuts from lamb carcasses.

Primal cut	R^2	RMSE	Variables in model[a]	Partial R^2
Shoulder	0.8832	1.011	HCW	0.8679
			CxsLength	0.0123
			ShRi	0.0010
			LegGap	0.0011
			LwSum	0.0009
Rack	0.7808	0.5418	HCW	0.7661
			TaSum	0.0109
			LegGap	0.0038
Loin	0.6804	0.5696	HCW	0.6635
			CxsLength	0.0037
			ShRi	0.0078
			TaSum	0.0022
			LwSum	0.0032
Leg	0.8260	0.8766	HCW	0.6906
			CxsLength	0.0908
			GroinA	0.0197
			LwSum	0.0186
			GrRtLeg	0.0064

[a]CxsLength = carcass length, LegGap = distance between the two legs, GrRtLeg = groin to right leg length, Groin A = groin area, ShRi = red color score for shoulder (adjusted for intensity), LnBi = blue color score for loin (adjusted for intensity), TwSum = sum of 20 total carcass width measurements, TaSum = sum of 20 total carcass area measurements, LwSum = sum of five leg width measurements, GrAngSum = sum of five groin angle measurements.

Table 6. Independent variables, R^2 , root mean square error (RMSE) values, and predicted residual sum of squares (PRESS) statistics for best-fit regression equations developed to predict percent carcass side yields using lamb vision system output plus hot carcass weight, developed in the present study and applied to the data from Brady et al. (2002).

Dependent variable	Present study				Brady et al. (2002)			
	R^2	RMSE	PRESS	Variables in model (coefficient)[f]	R^2	RMSE	PRESS	Variables in model (coefficient)[f]
Saleable meat yield, %[a]	0.676	0.0206	0.0686	HCW (-0.0021) CxsLen (0.000015) Sh/Ra ratio(0.26647) Tw ratio(-0.25329) GrRtLeg(0.000447) Lw1(0.00064) ShBi (0.53452)	0.594	0.0216	0.1188	HCW (-0.0018) CxsLen (0.00030447) Sh/Ra ratio(0.21675) Tw ratio(-0.14012) GrRtLeg(0.0000093) Lw1(0.00024) ShBi (1.50988)
Subprimal yield, %[b]	0.619	0.0168	0.0451	HCW (-0.00129) CxsLen (0.000087) Sh/Ra ratio(0.22107) Tw ratio(-0.21053) GrRtLeg(0.000273) Lw1(0.000311) ShBi (0.6423)	0.548	0.021	0.112	HCW (-0.00166) CxsLen (0.0003042) Sh/Ra ratio(0.21016) Tw ratio(-0.14084) GrRtLeg(-0.000008) Lw1(-0.000102244) ShBi (1.11035)
Fat yield %[c]	0.738	0.0205	0.0680	HCW (0.00267) CxsLen (-0.00016) Sh/Ra ratio (-0.27358) Tw ratio (0.2555) GrnAng1(0.00226) Lw1(-0.00076288) ShBi (-0.46843)	0.7542	0.0237	0.142	HCW (0.00287) CxsLen (-0.0003202) Sh/Ra ratio(-0.29372) Tw ratio(0.19025) GrnAng1(0.00227) Lw1(-0.00085889) ShBi (-1.56582)

[a]Saleable meat yield = subprimal cuts and lean trim from the leg, loin, rack, shoulder, and thin cuts as a percentage of chilled side weight.

[b]Subprimal yield = subprimal cuts from the leg, loin, rack, and shoulder as a percentage of chilled side weight.

[c]Fat yield = percentage of chilled side weight of fat from the production of subprimal cuts.

[f]HCW = hot carcass weight, CxsLen = carcass length, GrRtLeg = groin to right leg length, ShBi = blue color score for shoulder (adjusted for intensity), Sh/Ra ratio = ratio of the maximum rack width and maximum shoulder width, Tw ratio= ratio of the minimum body (shoulder, rack, loin) and the maximum body width, Lw1 = leg width measurement closest to the groin, GrnAng1= first groin angle measurement.

Table 7. Independent variables, R^2, root mean square error (RMSE), predicted residual sum of squares (PRESS) and partial R^2 for regression equations using lamb vision system (LVS) factors, HCW, and LMA and/or percent fat (PF) measurements taken with the video image analysis (VIA), to predict saleable meat [a] and subprimal [b] yields from lamb carcasses.

	R^2	RMSE	PRESS	Variables in model[c]	Partial R^2
LVS, HCW, and LMA:					
Saleable meat yield, %	0.6778	0.0205	0.0675	HCW	0.1711
				CxsLen	0.2866
				Sh/Ra ratio	0.0645
				Tw ratio	0.0716
				GrRtLeg	0.0471
				Lw1	0.0261
				LMA	0.0108
Subprimal yield, %	0.6411	0.0163	0.0425	HCW	0.1265
				Sh/Ra ratio	0.1764
				Tw ratio	0.1924
				GrAng1	0.0920
				LMA	0.0356
				ShBi	0.0099
				LW1	0.0082
LVS, HCW, and PF:					
Saleable meat yield, %	0.7189	0.0192	0.0587	% Fat	0.5258
				HCW	0.0650
				CxsLen	0.0677
				Sh/Ra ratio	0.0198
				Tw ratio	0.0101
				GrRtLeg	0.0247
				Lw1	0.0058
Subprimal yield, %	0.6562	0.0159	0.0401	% Fat	0.4678
				HCW	0.0627
				Sh/Ra ratio	0.0431
				Tw ratio	0.0197
				GrAng1	0.0483
				ShBi	0.0145
Lamb vision system, HCW, LMA and PF:					
Saleable meat yield, %	0.7189	0.0192	0.0587	% Fat	0.5258
				HCW	0.0650
				CxsLen	0.0677
				Sh/Ra ratio	0.0198
				Tw ratio	0.0101
				GrRtLeg	0.0247
				Lw1	0.0058
Subprimal yield, %	0.6562	0.0159	0.0401	% Fat	0.4678
				HCW	0.0627
				Sh/Ra ratio	0.0431
				Tw ratio	0.0197
				GrAng1	0.0483
				ShBi	0.0145

[a]Saleable meat yield: subprimal cuts and lean trim from the leg, loin, rack, shoulder, and thin cuts as a percentage of chilled carcass weight.
[b]Subprimal yield: subprimal cuts from the leg, loin, rack, and shoulder as a percentage of carcass side weight.
[c]HCW = hot carcass weight, CxsLen = carcass length, GrRtLeg = groin to left leg length, ShRi = red color score for shoulder (adjusted for intensity), ShBi = blue color score for shoulder adjusted for intensity, LMA = longissimus muscle area obtained from Video Image Analysis (VIA), Percent Fat= Overall percent fat in the 12th /13th rib interface obtained from VIA output, Sh/Ra ratio = ratio of the maximum rack width and maximum rhoulder width, Tw ratio= ratio of the minimum body width (shoulder, rack, loin) and the maximum body width, Lw1 = leg width measurement closest to the groin, GrAng1= first groin angle measurement.

Table 8. Descriptive statistics for longissimus muscle area (cm^2) values by method of measurement.

Method	n	Mean	SD	Minimum	Maximum
CSU – gridded [a]	147	16.54	2.15	12.10	22.42
VIA image 1 only [b]	149	16.38	2.33	12.08	22.90

[a] Measurement of the longissimus muscle area (LMA) accomplished by CSU personnel using a grid.

[b] Measurement of the longissimus muscle area (LMA) using the video image analysis (VIA), only picture 1 of each carcass was used for the percentage yield prediction equation.

Table 9. Accuracy: coefficient of determination (R^2) and residual standard deviation (RSD) for CSU – gridded[d] longissimus muscle area (LMA, cm^2) regressed on VIA measurements of LMA (cm^2).

	n	R^2	RSD
Image 1 only [a]	149	0.59	1.38
Image 2 only [b]	149	0.56	1.43
Image 3 only [c]	149	0.60	1.36

[a] Measurement utilizing the first picture of the set of three in the triple trigger procedure.

[b] Measurement utilizing the second picture of the set of three in the triple trigger procedure.

[c] Measurement utilizing the third picture of the set of three in the triple trigger procedure.

[d] Measurement of the LMA accomplished by CSU personnel using a grid.

Table 10. Repeatability: mean absolute differences (cm^2) and standard deviation (SD) for longissimus muscle area (LMA) using video image analysis (VIA).

Method	n	Mean Absolute [a] Difference (cm^2)	SD
Triple trigger [b]	149	0.13	2.35
Three placements [c]	149	0.15	2.41

[a] Mean absolute difference: Mean of the absolute difference (cm^2) between individual measurements and the average of those same measurements for each LMA

[b] Measurement obtained from three sequential images per longissimus muscle without moving the camera head between pictures.

[c] Measurement obtained from three images per longissimus muscle removing the camera head between pictures.

Table 11. Repeatability: variance components of all longissimus muscle area (LMA; cm^2) measurements using video image analysis (VIA).

Method of measurement	n	Variance due to [a]:			% of total variance due to:		Repeatability [d]
		Carcass (σ^2_c)	Error (σ^2_ε)	Total	Carcass	Error	
Triple trigger [b]	149	5.51	0.08	5.59	98.6	1.4	.986
Three placements [c]	149	5.77	0.09	5.86	98.4	1.6	.984

[a] σ^2_c = variance due to the carcass; σ^2_ε = residual variance = repeatability variation.

[b] Measurement obtained from three sequential images per longissimus muscle without moving the camera head between pictures.

[c] Measurement obtained from three images per longissimus muscle removing the camera head between pictures.

[d] Repeatability: calculated as (error variance + carcass variance)/total variance.

Literature Cited

Brady, A. S., K. E. Belk, S. B. LeValley, N. L. Dalsted, J. A. Scanga, J. D. Tatum, and G. C. Smith. 2002. An evaluation of the lamb vision system as a predictor of lamb carcass red meat yield percentage. J. Anim. Sci. In Press.

Cannell, R. C., J. D. Tatum, K. E. Belk, J. W. Wise, R. P. Clayton, and G. C. Smith. 1999. Dual-Component Video Image Analysis System (VIASCAN) as a predictor of beef carcass red meat yield percentage and for augmenting application of USDA Yield Grades. J. Anim. Sci. 77:2942-2950.

Cannell, R. C., K. E. Belk, J. D. Tatum, J. W. Wise, P. L. Chapman, J. A. Scanga, andG. C. Smith. 2002. Online evaluation of a commercial video image analysis system (Computer Vision System) to predict beef carcass red meat yield and for augmenting the assignment of USDA Yield Grades. J. Anim. Sci. 80:1195-1201.

Garrett, R .P., J. W. Savell, H. R. Cross, and H. K. Johnson. 1992. Yield Grades and carcass weight effects on the cutability of lamb carcasses fabricated into innovative style subprimals. J.Anim.Sci. 70:1829-1839.

Jones, S. D. M., L. E. Jeremiah, A. K. W. Tong, W. M. Robertson, and L. L. Gibson. 1992. Estimation of lamb carcass composition using an electronic probe, a visual scoring system and carcass measurements. Can. J. Anim. Sci. 72:237-244.

Steiner, R., D. J. Vote, K. E. Belk, J. A. Scanga, J. W. Wise, J. D. Tatum, and G. C. Smith. 2003. Accuracy and repeatability of longissimus muscle area measurements. J. Anim. Sci. In Press.

Steiner, R., A. M. Wyle, D. J. Vote, D. L. Roeber, R. C. Cannell, R. J. Richmond, K. Markey, J. W. Wise, M. E. O'Connor, R. R. Jones, K. E. Belk, J. D. Tatum, and G.

C. Smith. 2000. Real time augmentation of USDA Yield Grades application to beef carcasses using state-of-the-art VIA instrumentation. Final Report to National Cattleman's Beef Association, Englewood, CO. Colorado State University, Fort Collins, CO.

Purcell, W. D. 1995. Economic issues and potentials in lamb marketing: Keys to the future of the sheep industry. Sheep Goat Res. J. 11(3):92-105.

USDA. 1992. United States standards for grade of lamb, yearling mutton, and mutton carcasses. Agricultural Marketing Service, Livestock and Seed Division, Washington, DC.

USDA. 1996. Institutional Meat Purchase Specifications for fresh lamb and mutton. Agric. Marketing Service, USDA, Washington, DC.

Ward, C. E. 1998. Slaughter lamb pricing issues, evidence and future needs. Sheep Goat Res. J. 14(1):35-42.