THESIS

INSTRUMENT EVALUATION OF LAMB CARCASS YIELD AND QUALITY CHARACTERISTICS

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ABSTRACT

INSTRUMENT EVALUATION OF LAMB CARCASS YIELD AND QUALITY CHARACTERISTICS

An instrument system capable of predicting lamb carcass yield and simultaneously segregating carcasses into meaningful quality classes with accuracy and precision would advance the assessment of true carcass value and enhance production of a consumer preferred product. The objectives of this research were to: 1) Assist in the development of official performance standards, using methodologies acceptable to the United States Department of Agriculture (USDA), Agricultural Marketing Service (AMS), Livestock and Seed (LS) Program, for approving instruments to assess commercial lamb carcasses; 2) Gain approval for at least two commercial lamb instrument carcass assessment systems; 3) Determine consumer sensory panel ratings of American lamb meat; 4) Establish baseline tenderness of American lamb meat; 5) Initiate efforts to determine whether or not instruments may be used to assess lamb carcass quality parameters.

The USDA-AMS-LS intends to accept ovine carcass cutability measurements made by approved instruments. The USDA-AMS-LS intends to approve instrument systems that meet specific performance requirements for accuracy, precision, and repeatability for the prediction of saleable meat yield of lamb carcasses. In the present study lamb carcasses (N = 577) were identified at a lamb packing plant in Colorado over four different seasonal periods corresponding with differing times throughout the year in which production practices are known to differ. Carcasses selected for inclusion in the study encompassed the full range of USDA Yield Grades (YG; 1-5) and a wide range of hot carcass weights (15.87-60.27 kg). Lamb carcasses were evaluated using 3 Video Image Analysis (VIA) instruments and subsequently fabricated into boxed primals/subprimals. Carcasses were fabricated by experienced in-plant meat-cutters, supervised by Colorado State University (CSU) and USDA personnel. Carcasses were fabricated into the following subprimals and components: Neck; Foreshank (IMPS 210); Rack, roast ready, frenched PSO 3x1" (IMPS 204C); Shoulder, square-cut, boneless, tied (IMPS 208); Denver ribs, skirt-off (IMPS 209A); Loin, short-cut, trimmed PSO 0x0" (IMPS 232A); Flank untrimmed (IMPS 232E); Leg, hindshank (IMPS 233F); and Leg, shank-off, boneless, tied (IMPS 234A). Carcass components, including subprimals, lean trimmings, trimmed fat, bone, and connective tissue were weighed by CSU personnel to allow computation of carcass yields for contrast with instrument predictions. Foresaddle and hindesaddles weights were summed to determine a chilled carcass weight for each carcass. Carcasses were excluded from the trial if the total aggregate cut weight for each carcass was less than 98% of its' chilled carcass weight. The USDA-AMS-LS computed the ovine carcass cutability (OCC) yield by calculating the percentage of weight of closely trimmed subprimal/primal cuts to the chilled carcass weight. The OCC yield formula included the following subprimal/primal: neck, breast (IMPS 209), foreshank (IMPS 210), untrimmed flank (IMPS 232E), frenched rack (IMPS 204C), boneless square-cut shoulder (IMPS 208), loin (IMPS 232A), hindshank (IMPS 233F), and boneless leg (IMPS 234A). The sample population was divided into calibration and

validation groups containing equal proportions of all OCC yield levels present in the sample population. The USDA-AMS-LS provided USDA quality and yield carcass factors, OCC yield, hot carcass weight, chilled carcass weight, and subprimals and their components weights' to technology providers for the carcasses assigned to the calibration data set. Technology providers were allowed to use the calibration data set to develop or refine their OCC yield prediction equations. Technology providers submitted instrument predicted OCC yield values for the validation data set to USDA-AMS-LS. The USDA-AMS-LS computed the necessary statistics to determine if instrument systems met the requirements for approval. The approval of instruments investigated in this study for assessment of lamb carcass yield was still to be determined by USDA-AMS-LS at the completion of this study.

Whole-number expert Yield Grade (expert YG) was used to investigate mean differences between OCC yield, and yield of subprimals and their components. A decrease ($P < 0.0001$) of at least 0.9% in OCC yield for each numerical increase in expert YG was observed. As expert YG increased the proportion of trimmed fat produced from the fabrication of all subprimal cuts increased as well ($P < 0.05$). Decreasing proportions of subprimal yields were observed for all cuts, except flank, as expert YG increased. Expert YG correctly designated carcasses into cutability classes and classified the more wasteful carcasses into higher YG's. The ability of Research Management System-Computer Vision System (RMS-CVS) , one of the Video Image Analysis (VIA) systems investigate in this study, was compared to expert YG to the nearest-tenth. The RMS-CVS system explained 54.2% ($R^2 = 0.542$) of the variation in OCC yield with greater accuracy and precision than expert YG to the nearest-tenth, which explain 38.8% ($R^2 =

0.388) of the variability OCC yield. It is evident, through analysis in this study, that VIA systems presents a more accurate and precise evaluation method of OCC yield. The approval of VIA systems for assessment of salable meat yield of lamb carcass will give the American lamb industry an objective tool to determine true carcass value. Using VIA systems to make more accurate estimates of carcass composition creates potential to assist in the development of a value-based marketing system that will induce the production of leaner carcasses and ultimately a consumer-preferred product.

Consumer sensory panel evaluation and Warner-Bratzler shear force (WBSF) were used to characterize lamb tenderness, flavor, and overall acceptability, and to establish a baseline tenderness value for American lamb meat. A single block-ready loin (IMPS 232A) from one side of each carcass was collected from 300 total subsample carcasses. Six loin chops per carcass were used for consumer sensory panel and WBSF evaluations (three loin chops per method). Consumer sensory panels were conducted at three central locations in Colorado during the summer of 2010. Potential panelists were approached in the open and asked to voluntarily participate in an untrained consumer sensory panel. Procedures were approved by the Colorado State University Research Integrity and Compliance Review, Institutional Review Board (IRB). Consumers used a 15-cm unmarked line scale to rate samples for “like” or “dislike” for the attributes of tenderness, flavor, and overall acceptability (left = dislike, right = like).

There were no differences ($P > 0.05$) in consumer ratings for tenderness, flavor, and overall acceptability for samples from different USDA Quality Grade (QG) classes or from different seasonal periods. Predicted probabilities showed that consumers would rate samples in the “like” category 92% of the time or more for tenderness. Samples would be rated for flavor in the “like” category at least 80% of the time for samples from both QG’s. Loin chops collected during summer had the lowest probability of being rated in the “like” category for flavor at a 78% rate, although not statistically different ($P = 0.6570$) from samples collected over the remaining seasons with an 81% probability of being rated in the “like” category. Probability for overall “liking” of samples by consumers was not affected by QG ($P = 0.2741$) nor season ($P= 0.4395$) with samples from QG Choice and Prime being rated in the “like” category at least 87% of the time and over 83% of the time for all seasons.

Warner-Bratzler shear force values did not differ ($P = 0.3211$) for samples derived from QG Choice and Prime carcasses. Season did not have an effect on WBSF values for carcasses collected during different times of the year ($P = 0.3800$). Although, the interaction between QG and seasonal period had significant ($P = 0.0139$) effect on WBSF values. Samples derived from QG Prime carcasses produced during the spring had lower WBSF values than spring QG Choice ($P < 0.0049$), fall QG Choice ($P < 0.0309$), summer QG Prime ($P < 0.0060$), and winter QG Choice ($P < 0.0038$) carcasses. There was no difference ($P < 0.05$) on WBSF values for samples derived from carcasses of the remaining combination of QG and season. Based on this study, and using 4.4 Kg as the WBSF threshold value for defining “tender,” American lamb meat can be considered “very tender” among consumers that at least periodically purchase lamb at retail. The American lamb industry can use these results in marketing campaigns to increase consumer interest in American lamb meat.

Finally, models for prediction of eating quality parameters of lamb meat were developed using RMS-CVS system output. The approaches taken in this study did not allow the development of a model that could accurately and precisely predict eating qualities of American lamb meat. Linear models derived from RMS-CVS output data showed the best results, still with low capability to predict eating quality parameters of American lamb meat ($R^2 \leq 0.201$). Comparison between models derived from RMS-CVS output data and models derived from USDA QG factors for prediction of eating quality parameters of lamb meat were made by evaluation of R^2, RMSE, and PRESS statistics. Models developed to predict WBSF had the best performance among all eating quality parameters. Warner-Bratzler shear force value was used as the dependent variable, an objective measurement of tenderness. Models for prediction of tenderness, flavor, and overall acceptance used consumer response, a subjective measurement which explains in part the low performance of those models. Consumer response and WBSF data in the present study had a low range of variation which may explain for the low prediction power of the models tested. The halo effect, a cognitive bias whereby perception of one trait is influenced by the perception of another trait, or several traits, was present in the consumer sensory response data. Consumer response for tenderness, flavor, and overall acceptability of American lamb meat were highly correlated ($r \geq 0.69$). The prediction of characteristics such as flavor and overall acceptance was very difficult due to the inherited subjectivity of consumer preferences and idea of what represent a desirable product among different groups of consumers.

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LITERATURE REVIEW

Generally, red meat consumers are concerned with wholesomeness, sensory attributes, and the conditions under which meat products are produced (Issanchou, 1996). An emphasis on nutrition and health, saturated fat, cholesterol and obesity by consumers in the United States has changed the demand for food products, especially meats (Resurreccion, 2004). The American lamb industry has long been criticized for producing lambs that are too fat. Tatum et al. (1989) conducted a national survey of lamb carcass cutability traits which showed that the majority of U.S. lamb carcasses had excessive amounts of external fat. The American lamb industry must reverse the downward trend in lamb meat consumption. Consumer preferences evolved in the past decades to where consumers require meat with more lean and less fat (Stanford, 1998; Thatcher and Couchman, 1983). Subjective methods for predicting lamb carcass composition are rapid and reasonably inexpensive, but the lamb industry should adopt objective methods in order to more readily change lamb carcass composition to meet consumer demand (Stanford, 1998). It is in the American lamb industry's best interest to seek technologies that will induce production of lean lamb carcasses to more effectively meet consumer desires for product.

The American beef industry adopted VIA systems to improve accuracy and precision of beef carcass evaluation in an effort to achieve a more meaningful value-based marketing system. Cross et al. (1983) conducted the initial study to evaluate the first generation VIA system's capabilities as a grading device and ability to predict lean muscle in beef carcasses. After that first effort, many other studies were undertaken to evaluate the VIA system's ability to predict closely trimmed boxed beef, retail product yield and weight, *Longissimus* muscle area, augmented USDA Yield Grade (YG), preliminary YG and adjusted preliminary YG, USDA YG, USDA marbling score, and beef tenderness (Cannell et al., 2002; Cannell et al., 1999; George, 1996; Moore, 2010; Shackelford et al., 1998, 2003; Steiner, 2003; Vote et al., 2003). The USDA-AMS LS published beef carcass evaluation standards for instruments to determine *Longissimus* muscle area in 2001 (later revised in 2003), USDA YG in 2005, fat thickness in 2005 (later revised in 2007), and USDA marbling score in 2006 (Woerner and Belk, 2008). The American beef industry and USDA have recognized that grading accuracy, precision and consistency benefits all segments of the beef production and consumption supply chain and VIA systems are a useful tool to achieve these goals (Woerner and Belk, 2008).

Official Standards for Quality Grades of Lamb and Mutton Carcasses were initially issued and made effective on February 16, 1931. Since their implementation, the Official Standards were amended several times to accommodate changes. In 1967, Johnston et al. (1967) observed how carcasses of the same quality grade and weight differed widely in their yields of trimmed retail cuts and value. Differences in external and intermuscular fat were identified as the primary cause for discrepancies in yield between those carcasses (Johnston, 1967). Due to the findings from Johnston et al. (1967) and other authors, yield grade standards were adopted in 1969 with the purpose of segregating carcasses into cutability classes. The last revision to the quality and yield grade standards were made in 1992 as an effort to provide an improved communication tool to efficiently reflect consumer's preferences for lean meat products back to producers (USDA, 1992). A new tool is needed to measure lamb carcass composition, one that is accurate, precise and repeatable and able to function under commercial chain speeds. The VIA systems available today seem to be the best available option.

The potential of Video Image Analysis systems (VIA) to predict lamb carcass cutability yield has been investigated by various authors (Brady, 2003; Chandraratne, 2003; Cunha, 2004; Hopkins et al., 2004). In the U.S., Brady et al. (2003) investigated the lamb vision system (LVS), a VIA system, for its capability to accurately predict lamb carcass cutability, and therefore carcass value in a commercial setting. In follow-up, Cunha et al. (2004) validated the regression equations developed by Brady et al. (2003) to predict lamb carcass fabrication yields; assessed possible improvements to the accuracy and precision of those equations using the LVS hot carcass component (LVS-HCC) and the chilled *Longissimus* muscle (LM) imaging system (LVS-CCC); and assessed the repeatability of LM area measurements using the LVS-CCC system.

Video Image Analysis systems also have been evaluated for their ability to predict lamb carcass cutability traits in other lamb producing countries. Rius-Vilarrasa et al. (2009) compared the Meat and Livestock Commission's (MLC) EUROP classification system to the E+V VSS 2000 VIA system under commercial conditions in an abattoir in the UK. The E+V VIA system was capable of improving the prediction of lamb primal meat yields compared to the current MLC EUROP carcass classification system used in the UK abattoirs (Rius-Vilarrasa, 2009). Hopkins et al. (2004) investigated use of VIA systems in the Australian meat industry for their ability to precisely and accurately predict lean meat yield in lamb carcasses. In that study, Hopkins et al.(2004)

demonstrated that appropriate modeling using the VIA system offered a workable method for predicting lean meat yield automatically under commercial conditions.

A number of researchers have undertaken development of objective methods to measure or predict the eating quality of lamb meat. In these studies, a variety of technologies have been tested. Andrés et al. (2007) investigated the association between chemical composition and meat quality traits scored by trained sensory panel and absorbance data obtained from Near Infrared (NIR) spectroscopy. The NIR system accurately predicted intramuscular fat and water content (R^2 = 0.841 and 0.674, respectively), but it was only able to discriminate differences in sensory properties of the most extreme samples as rated by the trained sensory panel (Andrés, 2007). Cañeque (2004) examined relationships among several carcass quality measurements, chemical and physical measurements including muscle pH, lean color, moisture, water holding capacity, cooking loss, tenderness determined by WBSF method, and sensory panel evaluation of meat quality traits in light lamb carcasses; principal component analysis was used to quantify relationships among the previously mentioned parameters. The model developed by Cañeque et al (2004) was able to explain 74% of the total variability in meat quality parameters , although this technique does not have an industry wide application.

More simplistic practices, without the use of electronic equipments, have been investigated. Lambe et al. (2009) investigated the usefullness of simple post-mortem carcass measurements to be used as accurate predictors of composition and key meat quality traits of lamb carcasses to enable segregation of carcasses at the harvesting facility. The consideration of sex, Longissimus muscle area, and subcutaneous fat depth improved prediction of intramuscular fat; still, moderate accuracy in prediction of intramuscular fat and low to moderate accuracy in prediction of shear force values were achieved (Lambe, 2009). Despite the many efforts to develop an intrument that is non-destructive, non-invasive, accurate, precise, repeatable and that can operate under commercial conditions such efforts have not been yet proven acceptable for prediction of quality parameters of lamb meat.

Among sensory attributes, tenderness is often viewed as the most important characteristic (Bailey, 1972; Chandraratne et al., 2006; Cortez et al., 2006; Tornberg, 1996). Tenderness is influenced by muscle characteristics and the effects of the environment to which muscles are exposed postmortem (Maltin et al., 2003). Meat tenderness is affected by selective breeding and genotype, growth rate, nutrition, pre-harvest stress, muscle fiber type, connective tissue amount, ultimate muscle pH, muscle buffering capacity, and postmortem proteolyses (Maltin et al., 2003; Tornberg, 1996). Among genetic factors, it is well established that Callipyge phenotype in lambs increases Warner-Bratzler shear force values for all muscles (Kerth et al., 2003; Shackelford et al., 1997, 2004). Post-harvest interventions such as electrical stimulation, carcass chill rate, and length of aging period can improve meat tenderness (Geesink et al., 2001; Lee et al., 2000; Tornberg, 1996).

Sensory traits for lamb meat such as flavor, aroma, and tenderness can be influenced by age, breed, sex, diet, and slaughter weight (Arsenos, 2002). Oliver et al. (1967) reported significantly higher WBSF values for rib chops from ram carcasses than those from wether carcasses. In sensory panel evaluations using the *Longissimus lumborum* muscle of Uruguayan castrated male Corriedale lambs, eight out of 11 sensory attributes were affected by diet, including tenderness and flavor (Resconi, 2009). Breed also has been shown to have a significant effect on WBSF values (Hoffman et al., 2003). Safari et al. (2001) reported that the only sensory difference perceived by panelists for lamb meat of different genotypes was flavor strength. American consumers prefer lamb meat with a milder odor and flavor characteristics (Sañudo, 1997). Moreover, consumer ratings for lamb meat are subject to the cultural preferences and culinary habits of panelists (Sañudo, 1997).

Tenderness can be evaluated by objective methods, such as instrumental measurements and trained panels, or by subjective methods such as consumer sensory panels (Destefanis et al., 2008; Tornberg, 1996). Objective evaluation methods allow researchers to compare different treatments as well as ascertain their effects on a particular characteristic. However, they cannot provide information on product acceptability or on consumer preference for one kind of meat over another (Wheeler et al., 1997). Consumers are the ultimate user, and judge, of goods and can give the final verdict on a product's acceptance, including the acceptance of red meats (Munoz, 1993). Further, consumers are the ultimate arbiter of meat quality, with tenderness being one of the most important elements (Maltin et al., 2003). Thus, the ultimate evaluation for measuring consumer perception of the eating quality of lamb and sheep meat is to use consumers (Russell, 2005).

Sensory evaluation relates to the application of principles and methods to measure human responses to stimuli of different products (Sidel et al., 1981). Affective tests are used to measure a product's acceptance and preference through selection, ranking, or scoring of samples (Meilgaard, 1999; Sidel et al., 1981). Ideal participants of affective tests are naïve, untrained, and potential consumers of the product being tested (Meilgaard, 1999; Munoz, 1998). Due to factors mentioned previously, it is essential that the consumer questionnaire be clear and direct in its questions about the product attributes of interest and to use terms familiar to consumers to avoid confusion and potentially misleading responses (Meilgaard, 1999). However, consumer data alone often do not provide enough detailed information of a product's acceptance or rejection (Munoz, 1998, 1993; Sidel et al., 1981). Descriptive or instrumental data can be used to overcome the limitations of consumer information (Munoz, 1998).

The relationship between consumer sensory data and analytical data can be used to answer questions such as an instrument's potential to measure eating quality of meat (Andrés, 2007; Toscas et al., 1999), perception of tenderness (Boleman, 1997), consumer acceptance (Huffman, 1996), willingness-to-pay (Feuz, 2004; Platter, 2005), accuracy and repeatability of consumer panels (Wheeler et al., 2004), as well as threshold values for consumer acceptance (Miller, 2001). Griffin et al. (1992) used analytical data to interpret responses from a consumer sensory panel comprised of U.S. and foreign participants to determine the existence, and extent, of preferences for sensory properties of panelists with different cultural backgrounds with regard to meat from certain breeds and ages of sheep and goats. The supplementation of affective testing results with analytical data is essential to decipher consumers' responses and to identify interactions between variables that otherwise would be missed (Toscas et al., 1999).

Description, evaluation and production of "consumer-preferred" lamb carcasses is difficult (Carpenter, 1966). A top priority for the success of the lamb industry relies on its ability to deliver products that satisfy consumers expectations (Cortez et al., 2006).

More specifically, it is essential for the American lamb industry to produce a product that meets most consumers' expectations and demands. The American lamb industry also must assess the quality of its product before they begin marketing it to selective niche markets. The American lamb industry would benefit from an objective method for the classification of lamb carcasses into cutability classes that will induce the production of leaner lamb carcasses. The first objective of this project was to assist in the development of official performance standards for approving instruments to assess commercial lamb carcasses using methodologies acceptable to USDA-AMS-LS. Objective two was to gain USDA approval for at least two commercial lamb instrument carcass assessment systems. Therefore, in the current study, three different VIA systems were calibrated under commercial conditions at a lamb packing plant in Colorado. Consumer sensory panel and instrumental measurement data can be used in combination to decipher consumer's response and acceptance of American lamb meat. Thus, objectives three and four of the study were to determine consumer sensory panel ratings and to establish baseline tenderness for American lamb meat, respectively. In addition, consumer sensory panel and instrumental measurement data were used in combination with VIA system output data to analyze the instrument's capability to predict eating quality parameters, this being the fifth and final objective of this study.

RESEARCH OBJECTIVES

The objectives of this research were to:

1. Assist in the development of official performance standards, using methodologies acceptable to USDA-AMS-LS, for approving instruments to assess commercial lamb carcasses.

2. Gain approval for at least two commercial lamb instrument carcass assessment systems.

3. Determine consumer sensory panel ratings of American lamb meat.

4. Establish baseline tenderness of American lamb meat.

5. Initiate efforts to determine whether or not instruments may be used to assess lamb carcass quality parameters.

MATERIALS AND METHODS

CARCASS FABRICATION AND SAMPLE COLLECTION

Five hundred and seventy seven lamb carcasses were identified at a lamb packing plant in Colorado over four different seasonal periods corresponding with differing times throughout the year in which production practices are known to differ (Table 1). Carcass selection criterion was based on the assessment of hot carcass yield grade (YG) performed by two "expert" meat graders (field supervisors of USDA-AMS). Carcasses selected for inclusion in the study encompassed the full range of YG's and a wide variation of hot carcass weight (Figure 1). Hot carcasses were scanned using the Video Image Analysis (VIA) system VSS 2000 (E+V Technology GmbH, Am Heidering 14, D-16515, Oranienburg, Germany).

After hot carcass imaging and selection, lamb carcasses were individually identified and chilled for 24 to 48 hours. Following chilling, a USDA grader assessed each carcass and stamped it with a USDA Quality Grade and USDA Yield Grade. Expert USDA graders assigned USDA Quality Grade and Yield Grade factors ("Gold Standard" factors) to each carcass independent of the previous grader's assessment. The expert graders used a grading probe and whatever length of time was necessary to maximize the accuracy and precision of grade factor assignments. Carcasses were then ribbed between the 12th and 13th ribs and allowed time to "bloom" for approximately 30 minutes. Expert graders then called different USDA Quality Grade and Yield Grade factors as well as a final USDA Quality Grade and a final USDA Yield Grade for each carcass ("Gold

Standard" factors), in ribbed carcasses. The exposed ribeye surface was scanned by two VIA Systems: Computer Vision System (Research Management Systems, USA Inc., Fort Collins, Colorado, USA) and VBG 2000 (E+V Technology GmbH, Am Heidering 14, D-16515, Oranienburg, Germany) to assess cold carcass characteristics factors and to predict ovine carcass cutability (OCC). A tracing of the *Longissimus* muscle also was obtained using Mulberry paper for comparison with the VIA systems' output (data not presented). Carcasses were fabricated into subprimals and their components and respective weights were recorded for comparison with the VIA systems predicted values.

Carcasses were fabricated by experienced in-plant meat-cutters, supervised by Colorado State University and USDA personnel. Carcasses were fabricated into the following subprimals and components: Rack, roast ready, frenched PSO 3x1" (IMPS 204C); Shoulder, square-cut, boneless, tied (IMPS 208); Denver ribs, skirt-off (IMPS 209A); Foreshank (IMPS 210); Neck; Loin, short-cut, trimmed PSO 0x0" (IMPS 232A); Flank untrimmed (IMPS 232E); Leg, hindshank (IMPS 233F); and Leg, shank-off, boneless, tied (IMPS 234A). Carcass subprimal cuts that define OCC yield were selected by lamb industry representatives. All subprimals were trimmed to an approximate 1/3 cm level. Weights were recorded for all subprimal components including fat, bone, and connective tissue at each sequential step of the fabrication process. The weights of the foresaddle and hindsaddles were summed to determine chilled carcass weight. Carcasses were excluded from the trial if the total aggregate weight of all cuts for each carcass was less than 98% of its' chilled carcass weight.

A single block-ready loin (IMPS 232A) from one side of each carcass was collected from 300 total random subsample carcasses of the original total number of carcasses. Loin samples were identified with a tag containing carcass information and harvest date, vacuum packaged, and then transported to the Colorado State University Meat Laboratory. Samples were segregated according to harvest day and aged for 15 days postmortem at 2^{o}C. At the end of the aging period, samples were frozen (-20^{o}C) until used for consumer sensory panel and Warner-Bratzler Shear Force (WBSF) evaluation.

VIDEO IMAGE ANALYSIS INSTRUMENT EVALUATION

The USDA Agricultural Marketing Service, Livestock and Seed Progam (USDA-AMS-LS) computed ovine carcass cutability (OCC) yields by dividing weights of closely trimmed subprimal/primal cuts or components by the chilled carcass weight. The OCC yield formula included the following subprimal/primal: breast (IMPS 209), foreshank (IMPS 210), neck, untrimmed flank (IMPS 232E), frenched rack (IMPS 204C), boneless square-cut shoulder (IMPS 208), loin (IMPS 232A), hindshank (IMPS 233F), and boneless leg (IMPS 234A). The sample population was divided into calibration and validation groups containing equal proportions of all OCC yield levels observed in the study. The USDA-AMS-LS provided USDA Quality and Yield Grade factors, OCC yield, hot carcass weight, chilled carcass weight, and subprimal and components weights to technology providers for carcasses assigned to the calibration data set. Technology providers were provided the calibration data to develop or refine their instrument OCC yield prediction equation. Technology providers submitted instrument predicted OCC yield values for validation data to USDA-AMS-LS. The USDA-AMS-LS established three statistical evaluation methods to determine if instrument systems met the requirements for approval. The average residual (Standard = 0 ± 2%), the residual being the difference between the instrument predicted OCC yield and the actual OCC yield, was used to determine if bias was constant in predictions. The standard deviation of the residuals from the actual OCC yield (Standard ≤ 4% units) was calculated to assess the precision in instrument predictions. The slope of the residuals (Standard = 0.00 ± 0.05), using the residual from the actual OCC yield as the dependent variable (y-axis) and the average of the instruments OCC yield and actual OCC yield as the independent variable (x-axis) was used to establish if bias existed in the instrument prediction as average OCC increased.

VIDEO IMAGE ANALYSIS INSTRUMENTS

E+V VSS 2000

The E+V VSS 2000 system has the capability to automatically grade and classify sheep and lamb hot carcasses. The instrument is comprised of two camera systems for automatic acquisition of the carcass side and back view images. The instrument system is integrated into the slaughter line and can perform at line speeds up to 800 carcasses per hour. Image data are evaluated using special image processing software on a computer. The following information can be produced by the VSS 2000 system: conformation and fat class, weight and yield of the most valuable cuts, and derivation of sort criteria.

E+V VBG 2000

The E+V VBG 2000 system has the capability to automatically grade and classify sheep and lamb cold carcasses through analysis of the ribeye surface area exposed between the 12th and 13th ribs. The instrument is comprised of a single camera system for acquisition of the ribeye surface image. The instrument system is integrated into the slaughter line and can perform at industry standard line speeds. The instrument requires an operator to place the image capturing component of the system on the expose ribeye surface. The main parameters determined by the VBG 2000 are: yield grade, total area, fat/meat ratio and absolute areas, subcutaneous fat thickness opposite the ribeye (PYG), ribeye area, ribeye height and width.

RMS COMPUTER VISION SYSTEM

The Computer Vision System (CVS) consists of a single camera system for the analysis of the ribeye surface area exposed between the 12th and 13th ribs of chilled lamb carcasses. The CVS ribeye camera acquires an image of the ribeye at the grading stand. The instrument requires an operator to place the image capturing component of the system on the expose ribeye surface. It objectively measures ribeye area and shape, marbling percentage, fat thickness, lean/fat color, and predicts salable product yield.

LOIN CHOP FABRICATION

Frozen loins were fabricated into 2.54-cm loin chops using a band saw (Model 400, AEW-Thurne, AEW Engineering Co. Ltd, Norwich, England). Loins were separated into “high” (high $\geq$ Slight^{30}) and “low” (low $<$ Slight^{30}) marbling groups according to degree of marbling in the exposed *Longissimus* muscle as determined by expert USDA graders. Each loin yielded a minimum of six loin chops, of which one-half were randomly assigned to consumer sensory panel evaluation and one-half where assigned to WBSF evaluation. Eighteen loin chops from the high and eighteen loin chops from low marbling groups were randomly assigned to sensory panel and WBSF evaluation sessions. Each session was comprised of loins from 12 different carcasses, and each carcass contributed with 3 chops per session. Loin chops remained frozen (-20^{o}C) until used for evaluation in a consumer sensory panel evaluation or WBSF test.

WARNER-BRATZLER SHEAR FORCE (WBSF) PROTOCOL

Loin chops were thawed to an internal temperature of 5^{o}C, deboned, and trimmed free of subcutaneous fat. A Type K thermocouple (Omega Engineering Inc., Stamford, CT) was placed in the geometric center of each chop and the internal temperature was monitored during cooking using a microprocessor thermometer (model HH21, Omega Engineering Inc., Stamford, CT). Loin chops originated from the same carcass were cooked in groups (N = 3) to an internal temperature of 70^{o} C using electric grills (model GGR64, Salton, Inc., Mt. Prospect, IL) which simultaneously cooked chops from both sides. Following cooking, loin chops were cooled to room temperature (22^{o}C) and two cores, measuring 1.27 cm in diameter, were removed from each of the three chops representing each carcass parallel to the longitudinal orientation of the muscle fibers. Each core was sheared once, perpendicular to the muscle fiber orientation, using an Instron testing machine (model 4443, Instron, Corp., Canton, MA) fitted with a Warner-Bratlzer shear head (cross speed: 200 mm/min). Peak shear force measurements were recorded for each core and averaged to obtain a single shear force value for each loin from each carcass.

CONSUMER SENSORY PANEL

Loin chops from the 300 subsample lamb carcasses were evaluated using three chops per carcass for a total of 900 samples. A Type K thermocouple (Omega Engineering Inc., Stamford, CT) was placed in the geometric center of each chop and internal temperature was monitored during cooking using a microprocessor thermometer (model HH21, Omega Engineering Inc., Stamford, CT). Similar to the WBSF analysis, loin chops from the same carcass were cooked together on electric grills (model GGR64, Salton, Inc., Mt. Prospect, IL), that simultaneously heat the chops from both sides, until reaching a final internal temperature of 70° C. Following cooking, chops were wrapped in aluminum foil and maintained at 60^{o} C using a heated pan carrier (Model UPCH400-110, Cambro MFG. CO., Huntington Beach, CA) until served to panelists.

Untrained consumer sensory panels were conducted at three central locations:

- Larimer County Fair, Loveland, CO (N = 12)
- Colorado State Fair, Pueblo, CO (N = 12)
- Colorado State University Dept. of Animal Sciences, Ft Collins, CO (N = 1)

Sensory panel participants were approached in the open and asked to voluntarily participate in the untrained consumer sensory panel. Procedures were approved by the Colorado State University Research Integrity and Compliance Review, Institutional Review Board (IRB). Participants were presented with a Participant Recruitment Script explaining the purpose of the study and how to answer the questionnaire. Participants were screened to ensure that they were lamb meat consumers and asked to list how frequently they consumed lamb. Additionally, the questionnaire contained questions regarding gender, age, family income, and ethnicity to document sample demographics (Table 2). Participants were assigned to one of 25 testing groups, with a maximum of six participants per group session.

Samples were served to consumer panelist recruits with unsalted crackers and distilled water to cleanse the palate in between assessment of each individual sample. Samples were served in plastic cups with a sample number for identification. Samples were rated for tenderness, flavor, and overall acceptability using a 15.0-cm unstructured line scale for each individual attribute. The line scale was anchored on the left (0.0 cm) with the term "dislike" for that specific attribute, and anchored on the right side (15.0 cm) with the term "like" to represent the highest degree of acceptance for that specific attribute. Each participant evaluated 6 samples. Eeach sample was comprised of a 1.3 cm x 1.3 cm x 2.54 cm portion of the *Longissimus* muscle. Samples were randomized within session so that each consumer was presented with samples from 6 different carcasses and so that the same combination of sampled lambs was never repeated. *Longissimus* muscle samples from each carcass were sampled by three different consumers.

STATISTICAL ANALYSIS

Statistical analyses were performed using SAS (Version 9.2, SAS Institute Inc., Cary, NC). Summary statistics (e.g., mean, standard deviation, minimum value, maximum value, and range) were computed using the MEANS procedure. The REG procedure was used for multiple regression analysis and development of an OCC yield prediction equation to be used by the RMS VIA system (CVS). Dependent OCC yield (actual value) from carcasses assigned to the calibration data set were regressed on independent variables of CVS output. Stepwise, forward, and backward selection methods were used to determine which independent variables were common and significant ($P < 0.05$) for each model selection. The root mean square error (RMSE) and predicted residual sum of squares (PRESS) statistics were computed to assess precision of OCC yield prediction models. A best-fit model was selected based on simplicity, R^2, PRESS statistics, and RMSE values.

Actual values of OCC yields for carcasses assigned to the validation data set were used as a dependent variable and regressed on expert USDA Yield Grade to the nearest tenth (YG), with YG serving as the sole independent variable in the model using the REG procedure. In the same way as it was performed for YG, dependent actual OCC yields for carcasses assigned to the validation data set were regressed on predicted OCC yield values generated by the CVS system best-fit equation. The CVS predicted OCC yield served as the sole independent variable in the model for comparison with YG. Results from regression of actual OCC yield on CVS predicted values and YG were compared for accuracy and precision using r-square (R^2), root mean square error (RMSE), and PRESS statistics generated by the R option of the REG procedure.

Analysis of variance was performed using the GLM procedure. A predetermined significance level of ($P < 0.05$) was used for all comparisons. The main effects of whole-number expert YG on OCC yield, subprimal yield, percent fat derived from subprimal fabrication and total percent fat were assessed. Least Squares means (LS-means) were computed for the main effect of expert YG on all variables. When F-tests were significant, differences between means were separated using the PDIFF option.

Analysis of variance for consumer sensory response and WBSF also was performed using the GLM procedure. A predetermined significance level of ($P < 0.05$) was used for all comparisons. Carcasses of USDA QG Good (N = 7) were exclude from the subsample data set (N = 300) for evaluation of WBSF and consumer sensory response to avoid bias results due to the unbalanced representation of carcasses in that class. Main effects of USDA QG (QG) and seasonal period on WBSF values and consumer ratings for tenderness, flavor, and overall satisfaction were assessed. Peak internal loin chop temperature served as a covariate for WBSF and consumer rating analyses. Adjusted Least Squares means (LS-means) were computed for each main effect and two-way interaction between the fixed effects of QG and season. When F-tests were significant, differences between means were separated using the PDIFF option. The GLIMMIX procedure was used to calculate the probability that consumers would "like" samples for tenderness, flavor, and overall acceptability based on the conversion of their response to each sensory parameter into a binomial format. Sample ratings measuring greater than 7.5 cm on the 15-cm line scale were interpreted as "like" and sample ratings measuring less than or equal to 7.5 cm were interpreted as "dislike."

The correlation structure of the data was analyzed using the PROC CORR procedure and logistic regression equations were developed using the PROC LOGISTIC procedure. Generalized adjusted coefficients of determination were calculated for each model using the RSQUARE and CTABLE options of the LOGISTIC procedure. Predicted probability of acceptance values were calculated for consumer sensory ratings of tenderness, flavor, overall acceptability using USDA Choice and Prime QG and WBSF values present in the data. The statistical approach and rationale followed was as described by Platter et al. (2003). Binomial variables were the consumer sensory ratings for each sensory attributes (dislike ≤ 7.5 cm , like > 7.5 cm).

The REG procedure was used to develop models for prediction of WBSF and consumer sensory rating responses. The RMS CVS output data was used as independent variables. In the same way, expert USDA Quality Grade and carcass quality factors were used as independent variables. The model-selection methods used were forward, backward, and stepwise to determine which independent variables were common and significant ($P < 0.05$) for each model selection. The root mean square error (RMSE) and predicted residual sum of squares (PRESS) statistics were computed using the R option of PROC REG to assess accuracy and precision of WBSF and consumer response prediction models. Best-fit models were selected based on simplicity, R^2, PRESS statistics, and RMSE values. Consumer sensory responses and WBSF also were regressed on expert USDA Quality Grade and carcass quality factors using each parameter as sole independent variable in the model.

RESULTS AND DISCUSSION

OVINE CARCASS CUTABILITY YIELD

Descriptive statistics for the 577 carcasses in the sample population are presented in Table 3. Video Image Analysis instruments were tested on carcasses covering a full range of USDA Yield Grades. Whole-number expert USDA Yield Grade (YG) was used to investigate mean differences between ovine carcass yield, and yield of subprimasl and their components. Ovine carcass cutability yield (OCC) differed ($P < 0.0001$) by YG classes with decreasing OCC yield values as YG increased (Figure 1). A decrease ($P < 0.0001$) of at least 0.9% in OCC for each numerical increase in YG was observed. Differences in salable portions, expressed as percentage of cold carcass weight of rack (IMPS 204C), boneless shoulder (IMPS 208), Denver ribs (IMPS 209A), loin, (IMPS 232A), trimmed flank; boneless leg (IMPS 234A), and total trimmed fat also were evaluated by YG classes (Table 4). Rack salable yields did not differ ($P > 0.05$) for carcasses of YG 1 through YG 3 or between YG 4 and YG 5 carcasses. Yield grade 4 and YG 5 carcasses produced a lower yield of rack than YG 1, YG 2, and YG 3 carcasses ($P < 0.0001$). A substantial increase ($P < 0.0001$) in trimmed fat from the rack was observed with increase in YG, and YG 5 carcasses produced three times more trimmed fat than YG 1 carcasses.

Salable yields from the carcass shoulder differed ($P < 0.0006$) for all YG classes, with decreasing yields as YG increased. Shoulder trimmed fat increased ($P < 0.004$) as YG increased. Yield grade 1 through YG 5 carcasses had very similar yields of salable

Denver ribs and were not statistically different ($P > 0.05$), but greater ($P < 0.0001$) yields of trimmed fat were produced as YG scores increased.

Salable loin portions differed ($P < 0.0001$) among all YG classes with decreasing yields as carcass YG increased. Yield grade 4 and YG 5 carcasses produced equal percentages of trimmed fat from the loin, which were greater ($P < 0.0001$) than trimmed loin fat percentages for YG 1, 2, or 3 carcasses.

Boneless leg yields for YG 2 and YG 3 did not differ statistically ($P = 0.0904$), although they were numerically different. Boneless leg yield differed ($P < 0.001$) among YG 1, 4, and 5 classes with decreasing percentages as YG increased. Trimmed fat yields from the leg differed ($P < 0.0039$) for all YG classes with increasing values as YG increased numerically. The yield of trimmed flank lean presented an inverse relationship to YG compared to the other subprimals investigated. As YG increased, so did the yield for the flank. Yield grade 1 carcasses produced the lowest yields of trimmed lean from the flank compared to all other YG classes ($P < 0.005$). The yield of trimmed lean from the flank did not differ for the remaining YG classes ($P > 0.05$). A positive relationship between increased YG and trimmed fat yields from the flank was observed, even though a greater amount of lean from the flank was produced by fatter carcasses. The greater amount of lean trimmings from the flank produced by fatter carcasses was due to the fact that the flank was fabricated into a 50/50 percent lean and fat trimming. Differences ($P < 0.0001$) in trimmed fat yields from the flank were observed between all YG's except between YG 3 and YG 4 carcasses ($P = 0.1299$).

Results from this study illustrated how wasteful the production of over-fat lambs is with substantial increase in trimmable fat as YG scores increase. Data collected in this study was used by VIA instrument companies to refine their equations and to develop new equations for the prediction of OCC yield. Accuracy, precision and repeatability of the respective instruments are under evaluation performed by USDA-AMS-LS and may be approved based on their performance. The approval of VIA systems for assessment of salable meat yield of lamb carcass will give the American lamb industry an objective tool to determine true carcass value. More accurate estimates of carcass composition generated by VIA systems have the potential to assist in the development of a value-based marketing system which will induce production of leaner carcasses and ultimately a consumer-preferred product. The emphasis on the production of leaner lambs should have no negative effect on the eating quality of American lamb meat as was evidenced by a study conducted using a subsample of the sample population of this study.

VIDEO IMAGE ANALYSIS SYSTEM PERFORMANCE

Prediction of OCC yield by RMS CVS system is performed through analysis of the exposed surface of the ribeye between the 12th and 13th ribs of the carcass. The RMS CVS system's software calculate predicted OCC yield using a regression equation containing various measurements including exposed lean area, fat thickness opposite to the ribeye, and proportions of lean and fat on the exposed ribeye surface. The actual equation used by the RMS CVS system is not described in this study due to proprietary rights held by the company. The ability of RMS CVS system to determine OCC yield was compared to expert USDA YG to the nearest tenth (YG). Comparison between the two cutability measuring applications was performed on carcasses included in the validation data set (N=181) selected by USDA-AMS-LS. A greater proportion of the variation in OCC yield was explained with more accuracy and precision by the RMS

CVS system than by expert YG (Table 5). It is evident that the RMS CVS system represents a more accurate and precise way for predicting OCC yield and consequently yield of cuts selected by the American lamb industry to be included in the OCC yield equation than current USDA YG Standards. Approval of the VIA systems investigated in this study to determine OCC yield were performed by USDA-AMS-LS, and were not concluded at the completion of this study.

AMERICAN LAMB MEAT QUALITY EVALUATION

WARNER-BRATZLER SHEAR FORCE EVALUATION

Descriptive statistics for the 300 subsample carcasses which loin chops were derived from are presented in Table 6. Warner-Bratzler shear force (WBSF) values did not differ ($P = 0.3211$) between samples derived from USDA Quality Grade (QG) Choice and Prime carcasses. Season did not have an effect on WBSF values for carcasses collected during different times of the year ($P = 0.3800$). Although, the interaction between QG and seasonal period had significant ($P = 0.0139$) effect on WBSF values. Samples derived from QG Prime carcasses produced during the spring had lower WBSF values than spring QG Choice ($P < 0.0049$), fall QG Choice ($P < 0.0309$), summer QG Prime ($P < 0.0060$), and winter QG Choice ($P < 0.0038$) carcasses. There was no difference ($P < 0.05$) on WBSF values for samples derived from carcasses of the remaining combination of QG and season. A complete list with adjusted Least Squares means of WBSF values for carcasses of Choice and Prime QG collected during the different seasons is shown in Table 7.

CONSUMER SENSORY PANEL EVALUATION

Consumer ratings for tenderness did not differ for samples from different QG (*P* = 0.3405) or by seasonal period (*P* = 0.2849). The interaction between QG and seasonal period had no effect (*P* = 0.2402) on consumer ratings for tenderness. Consumer ratings for flavor did not differ across seasonal periods (*P* = 0.1493). Quality Grade did not influence (*P* = 0.2369) consumer ratings for flavor. There was no interaction effect (*P* = 0.1686) between QG and seasonal period on consumer ratings for flavor. Consumer ratings for overall acceptability did not differ for samples from different QG (*P* = 0.3508) or by season (*P* = 0.2572). The interaction between QG and seasonal periods also had no effect (*P* = 0.2838) on the overall acceptability of American lamb meat. Least Squares means and standard error for consumer sensory ratings across QG and seasonal periods are shown in Table 8.

Predicted probabilities of consumers rating samples in the “like” category were calculated using generalized mixed models with tenderness, flavor, or overall responses as the dependent variable. The effects of USDA QG and seasonal period on consumer response were evaluated. The probability of consumers rating samples in the “like” category for tenderness was not affected (*P* = 0.9388) by QG or season (*P* = 0.7690). Consumer ratings of tenderness for samples derived from QG Choice and Prime carcasses would be in the “like” category 93.91% and 93.65% of the time, respectively, and samples also would be rated as like at least 92% of the time for all seasons. Probability of samples being rated in the “like” category for flavor was not influenced by QG (*P* = 0.7639), and consumer rating responses should be rated as “like” over 80% of the time. Loin chop samples collected during summer had the lowest probability of being rated in the "like" category for flavor at a 78% rate, although not statistically different (*P* = 0.6570) from samples collect over the remaining seasons with an 81% probability of being rated in the "like" category. Probability for overall "liking" of samples by consumers was not affected by QG (*P* = 0.2741) nor season (P = 0.4395) with samples from QG Choice and Prime being rated in the "like" category at least 87% of the time and over 83% of the time for all seasons.

Analysis of the correlation structure of the data is presented in Table 9. There was no correlation (*P* > 0.05) between consumer sensory rating parameters and expert averaged USDA marbling scores, feathering, or flank streaking. Expert averaged USDA marbling scores had significant (P < 0.0001) correlation (r = -0.30) with WBSF value. A significant (*P* < 0.05) correlation (r = 0.11) between tenderness ratings and USDA on-line QG was observed. Warner-Bratzler value had moderate to low correlation with tenderness, flavor and overall acceptability ratings (r = -0.36, -0.16, and -0.24, respectively). Consumer sensory ratings had a high positive correlation amongst each other (r = 0.71 to 0.92). The halo effect was observed among consumer ratings of tenderness, flavor, and overall "like" or "dislike", where the perception of one trait was influenced by the perception of another trait, or traits.

Frequency distribution for consumer ratings of "like" or "dislike" of samples for tenderness, flavor, and overall acceptability are presented in Table 10. The predicted probability of consumers accepting tenderness of American lamb meat based on mean WBSF value is shown in Figure 3. The strength of the relationship between consumer acceptance of tenderness and WBSF values was weak (Max-rescaled R^2 = 0.1137). The WBSF model had moderate discriminatory power (c-statistic = 0.750) and correctly classified 92.7% of the observations. Results of our study show that the threshold for tenderness for American lamb loin chops is approximately 4.4 Kg WBSF value, such that there is a 50% chance consumers will rate samples acceptable for tenderness at that level. Results of our analysis produced results equal to those of Platter et al. (2003) for beef, with predicted probabilities of consumer acceptance of 50% at approximate WBSF value of 4.4 Kg, and similar to Shackelford et al. (1991) who reported WBSF threshold value of 4.6 Kg.

The probability curve for consumer overall acceptance of American lamb meat used WBSF values as the response function (Figure 4); expert QG, on-line QG, and averaged USDA marbling score did not generate models able to predict overall acceptance and were not plotted ($P > 0.05$). The strength of the relationship between consumer overall acceptance and WBSF values was weak (Max-rescaled $R^2 = 0.0806$) which was not surprising given the low average and narrow range of WBSF values for lamb loin chops in our study. The WBSF model had moderate discriminatory power (c-statistic = 0.681) and correctly classified 87.7% of the observations. The probability of consumers rating samples in the “like” or “dislike” categories for flavor could not be predicted by QG, expert or on-line, or by any other carcass quality factor investigated in this study. Plot of the predicted probability curves for overall acceptance of loin chops by consumers as derived from the cumulative logit response functions of average consumer ratings for tenderness and flavor are shown in Figure 5. The strength of the relationship between predicted consumer overall acceptance and observed flavor ratings (Max-rescaled $R^2 = 0.6774$) was stronger than that of tenderness (Max-rescaled $R^2 = 0.5206$). A very high discriminatory power was observed for flavor (c-statistic = 0.968) and tenderness (c-statistic = 0.910) models which classified samples in the right category 92.7% of the time.

The high levels of acceptance for tenderness of American lamb meat rated by consumers in this study are explained by the low WBSF values observed with a mean value of 2.01 kg. Even though loin samples of QG Prime carcasses collected during summer had the highest WBSF values (2.13 kg) they would still likely be considered “very tender.” The averaged WBSF value for American lamb loin samples observed in this study had lower WBSF values than USDA Select and upper two thirds USDA Choice beef tenderloin (*Psoas major* muscle) aged for 28 days (Gruber, 2006). Moreover, the average WBSF values for lamb loin chops was well below the “slightly tender” WBSF threshold for beef top loin steak values of 4.6 and 3.9 kg for retail and foodservice, respectively (Shackelford et al., 1991), and the “tender” category for beef top loin steaks with WBSF values ranging between 2.27 and 3.58 kg suggested by Boleman et al. (1997).

It has been suggested that a difference of at least 0.4 Kg in WBSF value must be present in order for consumers to detect differences in tenderness in intact meat samples (Miller, 1995). Huffman et al. (1996) and Destefanis et al. (2008) concluded that a change of at least 1.0 kg in WBSF value was needed for sensory panelists to find a noticeable difference between beef steaks. These studies help explain why there were no significant differences for consumer ratings of tenderness for samples from carcasses of different QG and different seasonal periods.

Based on this study, and using 4.4 Kg as the WBSF threshold value for defining “tender,” American lamb meat can be considered “very tender” among consumers that at least periodically purchase lamb at retail. The American lamb industry can use these results in marketing campaigns to increase consumer interest in American lamb meat.

DEVELOPMENT OF MODEL FOR PREDICTION OF EATING QUALITY PARAMETERS

The approaches taken in this study did not allow the development of a model that could accurately and precisely predict eating qualities of American lamb meat. Linear models derived from RMS CVS output data showed the best results, still with low capability to predict eating quality parameters of American lamb meat ($R^2 \leq 0.201$). Comparison between models derived from RMS CVS output data and models derived from USDA QG factors for prediction of eating quality parameters of lamb meat were made by evaluation of R^2, RMSE, and PRESS statistics (Table 11). The RMS CVS system used hot carcass weight, measurements of exposed lean and fat area, and various color measurements as independent variables in their models to predict eating quality parameters of American lamb meat. The actual equations used by the RMS CVS system are not described in this study due to proprietary rights held by the company. Models developed to predict WBSF had the best performance among all eating quality parameters. Warner-Bratzler shear force value was used as the dependent variable, an objective measurement of tenderness. Models for prediction of tenderness, flavor, and overall acceptance used consumer response, a subjective measurement which explained, in part, the low performance of those models. Jeremiah et al. (1998) came to the conclusion that it is futile to attempt to obtain a meaningful prediction of consumer acceptance of lamb meat based on carcass measurements. A total of 39 carcass parameters were regressed on consumer ratings of lamb meat resulting in models that could account for no more than 2% of the variation in consumer response (Jeremiah, 1998). In a similar study, Lambe et al. (2009) developed models with moderate accuracy for prediction of intramuscular fat and low accuracy to predict shear force values, all these with insufficient accuracies for application at a commercial level. Consumer response and WBSF data in the present study had a low range of variation which may explain the low prediction power of the models tested. The halo effect, a cognitive bias whereby perception of one trait is influenced by the perception of another trait, or several, was present in the consumer sensory response data. Consumer response for tenderness, flavor, and overall acceptability of American lamb meat were highly correlated ($r \geq 0.69$). The prediction of characteristics such as flavor and overall acceptance was very difficult due to the inherited subjectivity of consumer preferences and idea of what represent a desirable product among different groups of consumers.

CONCLUSION: POTENTIAL OPPORTUNITIES FOR THE U.S. LAMB INDUSTRY

Based on the extensive amount of detailed information collected during this study, a list of opportunities was compiled for consideration by the U.S. lamb industry as it seek ways to increase the per capita consumption of American lamb meat:

- A decrease in ovine carcass cutability yield was observed as USDA Yield Grade increased.
- Fatter lambs yielded less high value cuts.
- Increasing proportions of fat were produced as USDA Yield Grade increased.
- The production of leaner lambs will not affect consumer acceptance of American lamb meat.
- Video Image Analysis system investigated in this study gave better predictions of Ovine Carcass Cutability yield than current USDA Standards.
- American lamb meat can be marketed as extremely tender with an average shear force value of 2.01 kg.
- American lamb meat has an overall acceptability rate of 83% or higher among consumers that at least periodically purchase lamb at retail.
- Prediction of eating quality parameters of American lamb meat could not be achieved using instruments.

Table 1. Carcass collection dates

	Collection Date	Carcasses Fabricated	Loins Collected
Season		n	n
Fall	10/28/2009 – 11/02/2009	125	72
Winter	1/11/2010 – 1/15/2010	155	76
Spring	4/12/2010 – 4/16/2010	161	78
Summer	6/07/2010 – 6/11/2010	136	74
Total		577	300

Table 2. Demographic makeup of consumers surveyed

Trait	Factor	Frequency, %
Number of participants	150	
Ethnicity	White	81
	Hispanic	10
	Native American	4
	African American	2
	Asian	1
	Other ethnicity	2
Income	<$25,000	15
	$25,001 to 50,000	20
	$50,001 to 75,000	22
	>$75,000	37
Monthly lamb consumption	<1	70
	2 to 4	20
	4 to 6	7
	>6	3
Gender	Male	52
	Female	44
Age	18-30	30
	31-40	16
	41-50	26
	51-60	15
	Over 60	13

Table 3. Carcass weights, USDA Quality Grade factors, and USDA Yield Grade of lamb sample population

Trait	N	Mean	SD	Minimum	Maximum	Range
Hot carcass weight, kg	577	35.36	7.21	15.87	60.27	44.39
Chilled carcass weight, kg	577	34.91	7.18	16.00	60.03	44.03
Expert Yield Grade	577	3.27	1.28	0.60	7.10	6.50
Fat thickness, cm	577	0.66	0.32	0.05	2.79	2.74
Adjusted fat thickness, cm	577	0.74	0.40	0.05	4.89	4.83
Expert Quality Grade[a]	577	375.59	34.16	255	495	240
Carcass conformation score[a]	577	392.26	39.26	235	495	260
Leg conformation score[b]	577	12.08	1.28	7	15	8
Ribeye marbling[c]	577	343.71	87.74	100	825	725
Flank streaking[c]	577	389.65	89.07	185	750	565
Feathering[c]	577	379.49	78.49	225	685	460
Skeletal maturity[d]	577	154.34	10.46	115	195	80
Lean maturity[d]	577	148.72	11.73	110	205	95
Final maturity[d]	577	149.10	11.17	110	200	90

[a] 100 to 199 = Utility; 200 to 299 = Good; 300 to 399 = Choice; 400 to 499 = Prime.

[b] 15 to 13 = Prime, 12 to 10 = Choice, 9 to 7 = Good, 6 to 4 = Utility, 3 to 1 = Cull.

[c] 100 to 199 = Practically Devoid; 200 to 299 = Traces; 300 to 399 = Slight; 400 to 499 = Small; 500 to 599 = Modest; 600 to 699 = Moderate; 700 to 799 = Slightly Abundant; 800 to 899 = Moderately Abundant.

[d] 100 to 199 = Young Lambs, 200 to 299 = Older Lambs, 300 to 399 = Yearling Mutton, 400 to 499 = Mutton.

Table 4. Least Squares means and standard error means (SEM) for wholesale cut yields[a] and trimmed fat from wholesale cuts by expert whole-number USDA Yield Grade

	YG 1	YG 2	YG 3	YG 4	YG 5	SEM
Rack	5.442^{b}	5.513^{b}	5.415^{b}	5.179^{c}	5.056^{c}	0.020
Rack fat	1.082^{b}	1.754^{c}	2.278^{d}	2.687^{e}	3.326^{f}	0.033
Shoulder	13.842^{b}	13.353^{c}	12.928^{d}	12.411^{e}	11.576^{f}	0.052
Shoulder fat	3.811^{b}	5.076^{c}	5.956^{d}	6.427^{e}	6.912^{f}	0.061
Denver ribs	2.983^{b}	2.941^{b}	2.931^{b}	2.889^{b}	3.066^{b}	0.015
Breast fat	2.600^{b}	3.471^{c}	4.083^{d}	4.514^{e}	4.956^{f}	0.040
Loin	6.658^{b}	6.240^{c}	6.005^{d}	5.658^{e}	5.328^{f}	0.027
Loin fat	1.350^{b}	1.848^{c}	2.183^{d}	2.636^{e}	2.764^{f}	0.039
Leg	18.393^{b}	17.390^{c}	17.010^{c}	16.229^{d}	15.160^{e}	0.089
Leg fat	3.149^{b}	3.955^{c}	4.531^{d}	4.836^{e}	5.598^{f}	0.046
Flank	1.605^{b}	1.834^{c}	1.896^{c}	1.908^{c}	1.790^{c}	0.017
Flank fat	1.869^{b}	2.770^{c}	3.670^{d}	3.912^{d}	5.039^{e}	0.066
Total trimmed fat[g]	13.864^{b}	18.876^{c}	22.703^{d}	25.014^{e}	28.597^{f}	0.022

[a] Expressed as percentage of cold carcass weight.

[b,c,d,e,f] Means in the same row with different superscript letters are different ($P < 0.05$).

[g] Total percentage of all trimmed fat.

Table 5. Independent variable, $R^2$and root mean square error (RMSE), and predicted residual sum of squares (PRESS) statistics for equations developed to predict ovine carcass cutability (OCC) yield using RMS CVS predicted OCC yield value, and expert nearest-tenth USDA Yield Grade as sole independent variable

Dependent variable	R^2	RMSE	PRESS	Variable in model
OCC Yield	0.542	0.013	0.033	RMS CVS predicted OCC yield
	0.388	0.015	0.043	Expert nearest-tenth Yield Grade

Table 6. Carcass weights, USDA Quality Grade factors, and USDA Yield Grade of sampled lamb population used in consumer sensory ratings and tenderness tests

Trait	n	Mean	Range	SD
Hot carcass weight, kg	300	35.17	42.67	7.64
Cold carcass weight, kg	300	34.82	42.65	7.57
Expert Yield Grade	300	3.28	6.45	1.39
Fat thickness, cm	300	0.67	2.74	0.36
Adjusted fat thickness, cm	300	0.76	4.83	0.49
Expert Quality Grade[a]	300	374.25	235	35.84
Carcass conformation score[a]	300	389.96	255	41.47
Leg conformation score[b]	300	12.03	8	1.35
Ribeye marbling[c]	300	339.28	725	94.67
Flank streaking[c]	300	392	530	90
Feathering[c]	300	379.38	390	81.41
Skeletal maturity[d]	300	154.50	70	11
Lean maturity[d]	300	149.05	95	12.42
Final maturity[d]	300	149.45	90	11.98

[a] 100 to 199 = Utility; 200 to 299 = Good; 300 to 399 = Choice; 400 to 499 = Prime.

[b] 15 to 13 = Prime, 12 to 10 = Choice, 9 to 7 = Good, 6 to 4 = Utility, 3 to 1 = Cull.

[c] 100 to 199 = Practically Devoid; 200 to 299 = Traces; 300 to 399 = Slight; 400 to 499 = Small; 500 to 599 = Modest; 600 to 699 = Moderate; 700 to 799 = Slightly Abundant; 800 to 899 = Moderately Abundant.

[d] 100 to 199 = Young Lambs, 200 to 299 = Older Lambs, 300 to 399 = Yearling Mutton, 400 to 499 = Mutton.

Table 7. Least Squares means (Mean) and standard error means (SEM) for Warner-Bratzler shear force value (Kg) of *Longissimus* muscle at 15 days postmortem for USDA Quality Grade (QG) Choice and Prime carcasses collected during different seasonal periods (Season)

Season	QG	n	Mean	SEM
Fall	Choice	56	1.99^{a}	0.065
Fall	Prime	12	1.98^{ab}	0.142
Winter	Choice	63	2.09^{a}	0.061
Winter	Prime	13	1.98^{ab}	0.135
Spring	Choice	61	2.08^{a}	0.062
Spring	Prime	16	1.69^{b}	0.122
Summer	Choice	50	1.92^{ab}	0.069
Summer	Prime	22	2.13^{a}	0.104
Total	-	293	2.01	0.028

^{a,b} Means within a column with different superscripts differ ($P < 0.05$).

Table 8. Least Squares Means (Means) and standard error means (SEM) for sensory traits[†] for sampled carcasses of USDA Quality Grade (QG) Choice and Prime collected during different seasonal periods

		Tenderness		Flavor		Overall	
Trait	n	Mean	SEM	Mean	SEM	Mean	SEM
QG							
Choice	230	10.65	0.127	9.50	0.136	10.05	0.130
Prime	63	10.92	0.251	9.86	0.269	10.32	0.257
Season							
Fall	68	10.57	0.309	9.60	0.332	10.07	0.316
Spring	77	11.24	0.269	10.24	0.289	10.64	0.275
Summer	72	10.72	0.245	9.42	0.263	9.92	0.251
Winter	76	10.61	0.291	9.45	0.313	10.10	0.299
Total	293	10.71	0.111	9.60	0.120	10.12	0.114

[†] Sensory traits were rated by panelists using a line scale anchored on the left (0.0 cm) with the term "dislike" for that specific attribute, and anchored on the right side (15.0 cm) with the term "like" to represent the highest degree of acceptance for that specific attribute

Table 9. Simple correlation coefficients of mean consumer sensory ratings, averaged shear force values (WBSF), and carcass quality factors

Trait	Flavor	Overall	WBSF	Lean Maturity	Maturity	Marbling	Feathering	Streaking	Conformation	Leg Score	Expert QG	USDA QG
Tenderness[a]	0.70**	0.83**	-0.36**	-0.02	-0.02	0.10	0.03	0.05	-0.05	-0.02	0.04	0.11*
Flavor[a]	-	0.92**	-0.16*	0.10	0.10	0.10	0.10	0.09	0.07	0.06	0.08	0.09
Overall[a]	-	-	-0.24**	0.06	0.05	0.07	0.07	0.06	0.02	0.03	0.06	0.09
WBSF[b]	-	-	-	0.07	0.07	-0.30**	-0.06	-0.10	-0.13*	-0.12*	-0.18*	-0.20*
Lean Maturity	-	-	-	-	0.98**	0.20*	0.27**	0.19*	0.33**	0.33**	0.20*	0.06
Maturity[c]	-	-	-	-	-	0.19*	0.26**	0.21*	0.34**	0.33**	0.21*	0.06
Marbling[d]	-	-	-	-	-	-	0.58**	0.47**	0.51**	0.47**	0.56**	0.31**
Feathering[e]	-	-	-	-	-	-	-	0.56**	0.47**	0.42**	0.59**	0.37**
Streaking[f]	-	-	-	-	-	-	-	-	0.53**	0.47**	0.90**	0.62**
Conformation[g]	-	-	-	-	-	-	-	-	-	0.91**	0.71**	0.40**
Leg Score[h]	-	-	-	-	-	-	-	-	-	-	0.65**	0.40**
Expert QG	-	-	-	-	-	-	-	-	-	-	-	0.62**
USDA QG[i]	-	-	-	-	-	-	-	-	-	-	-	-

[a] Tenderness, Juiciness, and Overall Acceptability ratings (0-cm = dislike, to 15-cm = like); [b] Warner-Bratzler shear force (WBSF) = 15-d shear force value.

[c] Matury = averaged final maturity score assigned by expert USDA grader.

[d] Marbling score = averaged expert marbling score.

[e] Feathering score = averaged expert feathering score.

[f] Streaking score = averaged expert flank streaking score.

[g] Conformation score = averaged expert carcass conformation score.

[h] Leg score = averaged expert leg conformation score.

[i] USDA QG = in-house USDA Quality Grade.

$^{**}P < 0.0001$

$^{*}P < 0.05$

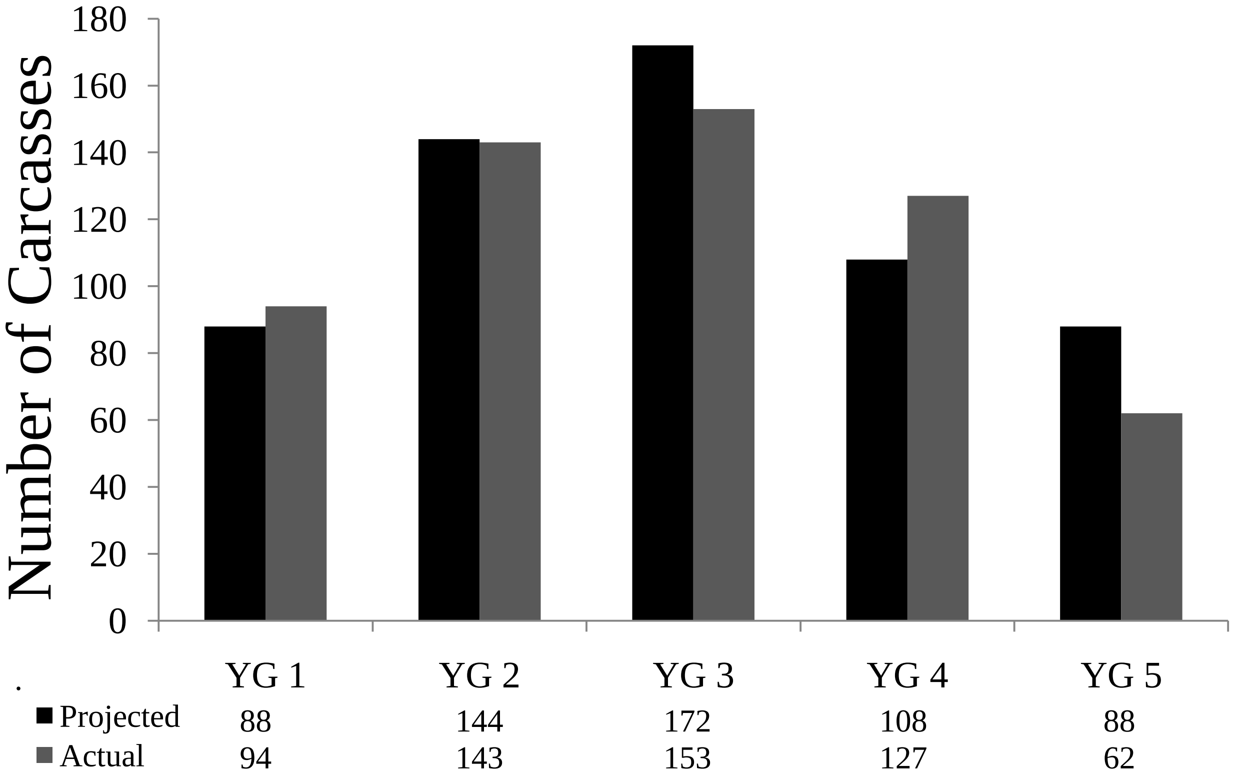
Table 10. Frequency distribution for consumer ratings[†] of samples for tenderness, flavor and overall acceptability

Sensory Trait	Tenderness		Flavor		Overall	
	Like	Dislike	Like	Dislike	Like	Dislike
N	275	18	238	55	258	35

[†] Sample ratings measuring greater than 7.5 cm on the 15-cm line scale were interpreted as “like” and sample ratings measuring less than or equal to 7.5 cm were interpreted as “dislike”

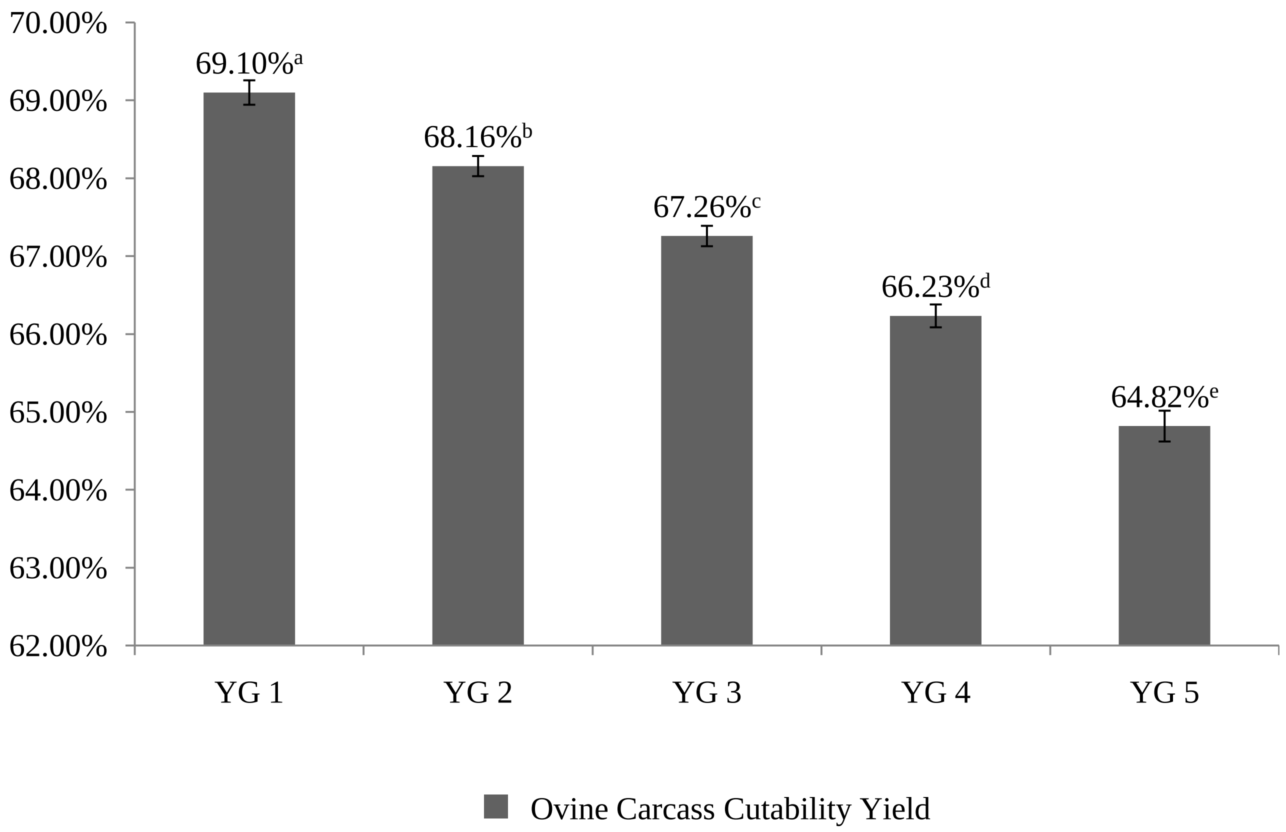
Table 11. Independent variables, $R^2$and root mean square error (RMSE), and predicted residual sum of squares (PRESS) statistics for best-fit regression equations developed to predict Warner-Bratzler Shear Force (WBSF), and sensory attributes (Tenderness, Flavor, and Overall acceptance) of American lamb meat using RMS CVS output data, and expert USDA Quality Grade factors (USDA QG)

	RMS CVS System				USDA QG			
Dependent variable	R^2	RMSE	PRESS	Variables in model	R^2	RMSE	PRESS	Variables in model
WBSF	0.201 ($P < 0.0001$)	0.479	69.765	13	0.166 ($P < 0.0001$)	0.497	77.413	Lean Maturity Flank Streaking Expert QG Ribeye marbling Feathering Leg conformation score On-line QG
Tenderness	0.113 ($P < 0.0009$)	1.861	1029.693	12	0.046 ($P < 0.0070$)	1.916	1121.512	Conformation score Ribeye marbling Leg conformation score On-line QG
Flavor	0.095 ($P < 0.0005$)	2.018	1193.766	8	0.019 ($P > 0.0539$)	2.087	1320.819	Final maturity On-line QG
Overall acceptance	0.077 ($P < 0.0041$)	1.931	1091.872	8	0.018 ($P > 0.1464$)	1.994	1211.708	Skeletal maturity Final maturity On-line QG



	YG 1	YG 2	YG 3	YG 4	YG 5
■ Projected	88	144	172	108	88
▨ Actual	94	143	153	127	62

Figure 1. Carcass selection schedule



[a,b,c,d,e]Means with a different superscript letter differ, ($P < 0.05$).

Figure 2. Least square means for ovine carcass cutability yield of carcasses sorted by expert whole-number yield grade.

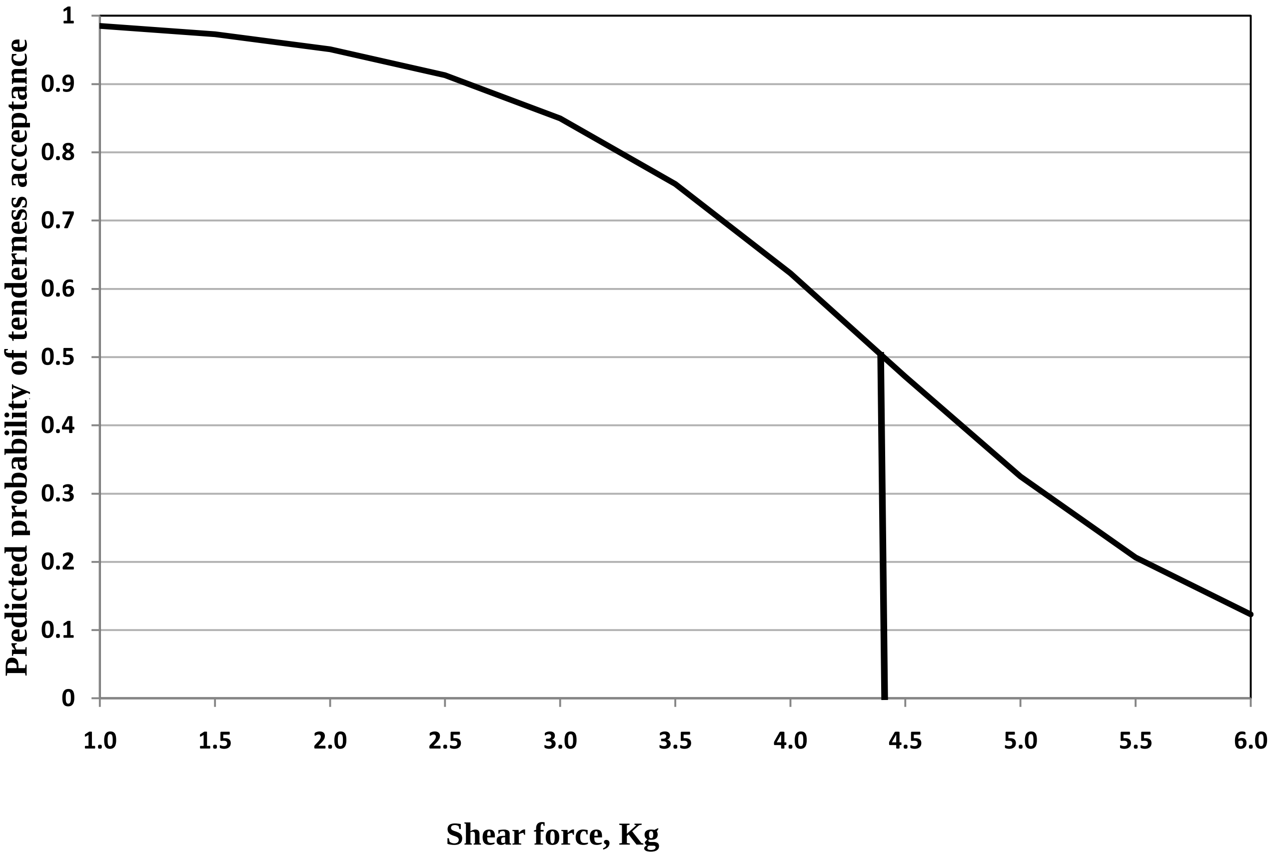


Figure 3. Predicted probability of consumers' acceptance of tenderness of American lamb meat based on mean Warner-Bratzler shear force value.

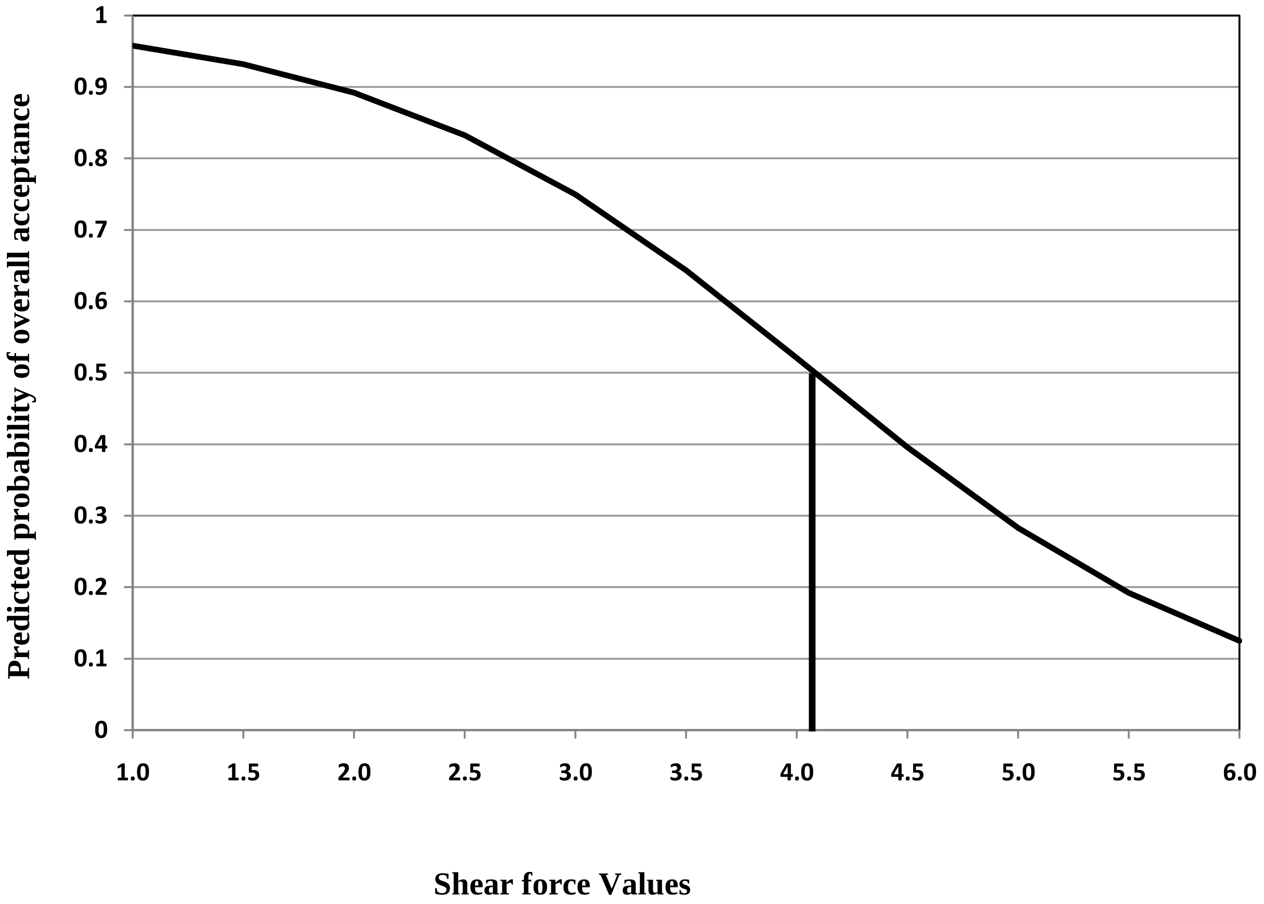


Figure 4. Predicted probability of consumers overall acceptance of American lamb meat based on mean Warner-Bratzler shear force values.

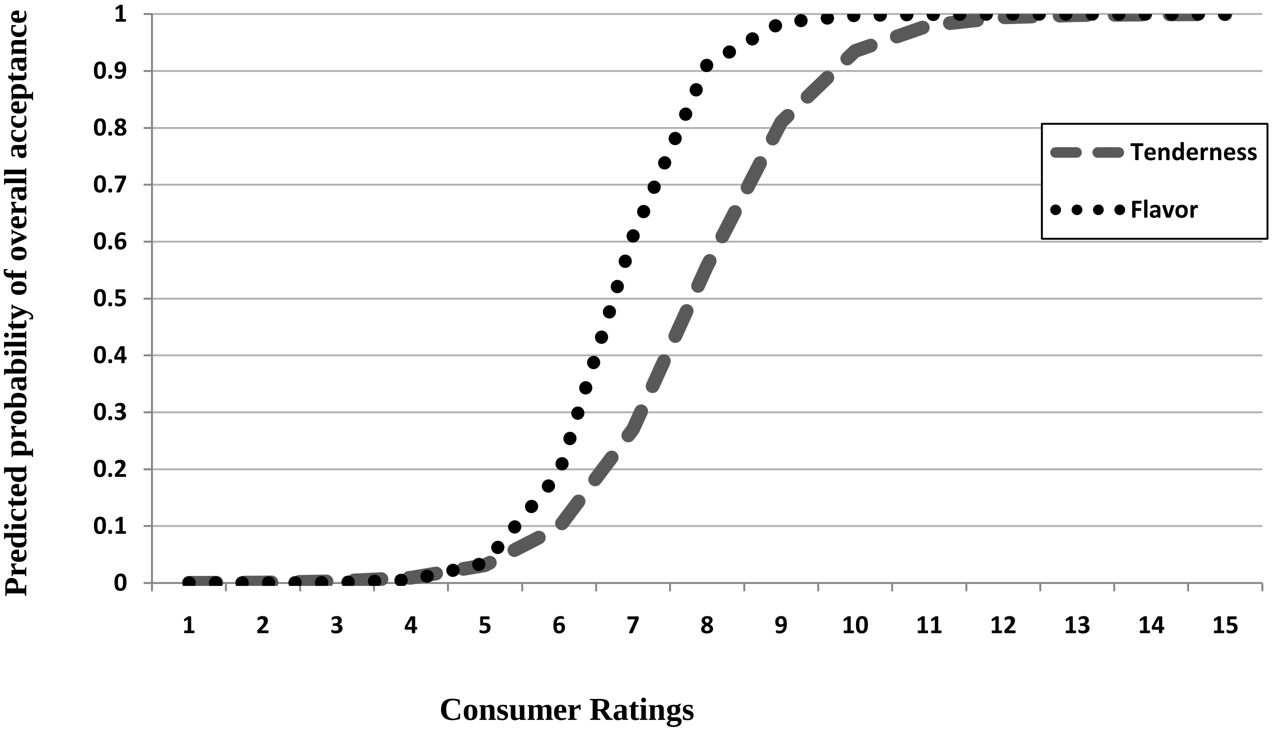


Figure 5. Predicted probability of consumer overall acceptance of loin chops by mean consumer rating for tenderness and flavor. Consumer like to dislike rating for tenderness and flavor as follows: 15 = like and 1 = dislike.

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