DISSERTATION

INSTRUMENT GRADING OF BEEF

Submitted by

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY DEREK JASON VOTE ENTITLED INSTRUMENT GRADING OF BEEF BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

INSTRUMENT GRADING OF BEEF

A study was conducted to determine the viability of the VIAscan Beef Carcass System (BCS) and/or Computer Vision System equipped with a BeefCam module (CVS BeefCam) to predict the fabrication yields of Uruguayan beef carcasses and the CVS BeefCam to segregate Uruguayan beef carcasses into groups that differ in Warner-Bratzler shear force (WBSF) values. Uruguayan National Institute of Meat (INAC) grades, USDA yield grade, CVS BeefCam, BCS, and combined CVS BeefCam and BCS output, respectively, accounted for 1) 35, 37, 41, 49, and 53% of the variation in commodity trimmed saleable meat yield (SMY); 2) 36, 41, 45, 52, and 58% of the variation in closely trimmed SMY; 3) 37, 52, 55, 58, and 66% of the variation in very closely trimmed SMY; and 4) 36, 53, 57, 59, and 69% of the variation in extra closely trimmed SMY. Correlation coefficients between WBSF values and CVS BeefCam output variables for lean color obtained approximately 50 min after ribbing were larger when carcasses considered to be dark cutters by visual appraisal were excluded rather than included. Output variables from the CVS BeefCam including lean L*, a*, and b* collected for steer and heifer carcasses (n = 178) and lean L*, a*, b*, and fat L* collected for mature cow carcasses (n = 107), were effective for segregating carcasses not considered to be dark cutters by visual appraisal into groups that differed ($P < 0.05$) in WBSF values. Classification of carcasses using CVS BeefCam output variables could help identify more uniform groups of steaks with respect to tenderness from Uruguayan beef carcasses. Another study was conducted to determine if reflectance measurements made in the near-infrared region of the spectrum were additive to reflectance measurements made in the visible region of the spectrum for predicting WBSF values. Reflectance measurements obtained in the near-infrared region of the spectrum were correlated with WBSF values, however, these measurements were not additive to the predictive ability of reflectance measurements made in the visible portion of the spectrum when the use of broad-band wavelength filters were simulated.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

OBJECTIVES OF DISSERTATION

The objectives of this dissertation were:

(1) To evaluate the effectiveness of the VIAscan Beef Carcass System (hot carcass system) and the CVS BeefCam (chilled carcass system), used independently or in combination, to predict Uruguayan beef carcass fabrication yields.

(2) To evaluate the effectiveness of the CVS BeefCam to segregate Uruguayan beef carcasses into groups that differ in the Warner-Bratzler shear force values of their longissimus steaks.

(3) To determine if reflectance measurements made in the near-infrared region of the spectrum were additive to reflectance measurements made in the visible region of the spectrum for predicting beef tenderness.

CHAPTER II

OVERVIEW OF BEEF GRADING SYSTEMS

The role of beef carcass grading systems is to classify, sort, or rank beef carcasses according to factors that describe the physical differences found between carcasses that are meaningful to those that produce, trade, and consume the meat from them. Generally, the factors that are measured when determining a beef carcass grade relate to the amount of edible product that can be produced from a beef carcass (cutability) and to the palatability (tenderness, juiciness, and flavor) of the edible portion of a beef carcass. If a grading system can effectively combine factors related to yield and palatability, then carcasses with similar characteristics can be more effectively marketed. Ultimately, a grading system then serves as a mechanism to pass information from the consumer level to the producer level of the industry about which types of carcasses are in the highest demand. Ideally, this information transfer can occur on an individual animal or carcass basis so that a value-based marketing system can be established. Also, because of the speed at which commercial beef packing plants operate, it is important that grades be applied in a short period of time and in a manner that both producers and consumers trust.

While beef grading systems share the common goal of providing a means to facilitate trade, they vary considerably among different countries in the factors that are measured and in the way that they are applied because not all consumers have the same preferences for beef. In the U.S., beef carcass grades are applied by personnel of the USDA-AMS, serving as an unbiased third party. Separate grades are applied to carcasses to reflect differences associated with meat yield (yield grades) and palatability (quality grades). In applying USDA yield grades, USDA graders take into account the external fat thickness, longissimus muscle area (LMA) between the 12th and 13th ribs in relation to the hot carcass weight (HCW), and the percentage of HCW that is comprised of kidney, pelvic, and heart fat (USDA, 1997). USDA graders then combine these subjective estimates to apply one of a possible five whole-number yield grades to a carcass. In applying USDA quality grades, USDA graders take into account the skeletal and lean maturity as well as the amount of marbling in the longissimus muscle (LM) between the 12th and 13th ribs. USDA graders balance the scores of maturity and marbling (taking into account lean firmness) to apply a single quality grade to a carcass (USDA, 1997).

Beef grading systems outside the United States.

South Korea uses a system similar to that of the U.S. for both quality and yield grades. There are four South Korean quality grades (1+, 1, 2, and 3) and they are based upon a combination of meat and fat color, marbling, maturity (as determined by the ossification of bone and cartilage), and lean texture (Korean Animal Products Grading Service, 1993). South Korean yield grades are determined by first using the following regression equation, yield = 65.834 – (0.393*fat thickness opposite the LM; mm) + (0.088* LMA; cm^2) – (0.008*chilled carcass weight; kg) to predict the percentage of closely trimmed ($\leq$ 0.5 cm) boneless retail cuts yielded from a carcass (Korean Animal Products Grading Service, 1993). Then carcasses are classified into one of three yield grades based on the predicted yield value (Korean Animal Products Grading Service, 1993). Carcasses with a predicted yield value of greater than 69 receive the A grade, carcasses with a predicted yield value of 66 to 69 receive the B grade, and carcasses with a predicted yield value of less than 66 receive the C grade (Korean Animal Products Grading Service, 1993). Also, in South Korea, quality and yield grades are coupled such that carcasses receive both a quality grade and a yield grade. That system does not distinguish carcasses according to sex characteristics.

The grading system in Japan is similar to that of South Korea. For yield grades, a regression equation is used to predict percentage meat yield of a carcass. This equation uses measurements obtained between the 6th and 7th ribs and is as follows: Percent yield = 67.37 + (0.130*LMA, cm^2) + (0.667*rib thickness, cm) – (0.025*cold left side weight, kg) – (0.896*subcutaneous fat thickness, cm); the yield grades are then applied according to the predicted yield percentage (Japan Meat Grading Association, 1988). Carcasses with a predicted yield percentage equal to or greater than 72% receive the A grade, carcasses with a predicted yield percentage equal to or greater than 69% and less than 72% receive the B grade, and carcasses with a predicted yield percentage less than 69% receive the C grade (Japan Meat Grading Association, 1988). The Japanese quality grading system is based on a subjective scoring system where there is one of a possible five scores assigned for each factor including, marbling, lean color and brightness, lean firmness and texture, and fat color and luster (Japan Meat Grading Association, 1988). Individual factor scores are then combined such that the final quality grade is equal to the lowest score given among the four factors (Japan Meat Grading Association, 1988).

Canada has adopted a system to mimic those grades, especially quality grades that are applied in the U.S. In total, there are 13 possible Canadian beef quality grades. The Canadian "A" and Prime grades are applied to youthful carcasses that meet a minimum marbling score and fat thickness specification, have an adequate amount of muscling and white fat, and have normal bright lean color (Canada Agricultural Products Act, 1992). The minimum marbling requirement for Canada Prime corresponds with the USDA marbling score of Slightly Abundant^{00}, the minimum marbling requirement for the AAA grade corresponds with the USDA marbling score of Small^{00}, the minimum marbling requirement for the AA grade corresponds with the USDA marbling score of Slight^{00}, and the minimum marbling score for the A grade corresponds with the USDA marbling score of Traces^{00}. The Canadian "B" grades are for youthful carcasses that do not otherwise meet the requirements for the "A" grades. The B1 grade is for carcasses that do not meet the minimum marbling requirements for the A grade, the B2 grade is for carcasses that have yellow fat, the B3 grade is for carcasses with inferior muscling, and the B4 grade is for carcasses with dark colored lean. Canadian "D" grades are for mature carcasses and the "E" grades are for bull or stag carcasses. Typically the "D" and "E" grades of carcasses are traded as ungraded product.

There are three Canadian yield grades (1, 2, and 3) that are based on an estimate of the percentage yield of lean meat derived from the primal cuts and which are applied only to carcasses receiving quality grades of Canada Prime, AAA, AA, and A (Canada Agricultural Products Act, 1992). These yield grades are determined by measuring the fat thickness opposite the LM and the length and width of the LM. As in the U.S., the grading of beef carcasses is voluntary, but is performed by personnel of the Canadian Beef Grading Agency (a privatized organization) and monitored by the Canadian government, whereas U.S. grading is both performed and monitored by USDA-AMS personnel.

The European Union (EU) has established a beef carcass grading system, known as the EUROP grading scheme, that differs substantially from the USDA grading system. Carcasses are classified initially as steers, heifers, cows, young bulls, and mature bulls (Office for Official Publications of the European Communities, 1981). Then carcasses are placed into groups based on a grid of subjective scores for muscle conformation and fatness (Office for Official Publications of the European Communities, 1981). There are eight muscle conformation scores and seven fatness scores, and thus, in total, carcasses of the same type (sex and age) can be classified into one of 56 possible groups in the classification grid (Office for Official Publications of the European Communities, 1981). Typically, the EU grades are applied by packing plant personnel trained to apply these grades, but they also may be applied by personnel of an independent institution (Borggaard et al., 1996). The Danish Meat Research Institute has developed a video image analysis system that can accurately predict the muscle conformation and fatness scores (Borggaard et al., 1996) and that is also used by some of the European beef packing plants.

Brazil, Argentina, and Uruguay have adopted beef grading systems similar to that used by the EU. These South American countries include an estimate of chronological age in their classification scheme by also grouping carcasses according to the number of permanent incisors that the animal had. Carcasses then receive subjective scores for muscle conformation and fatness. For the EU, Brazil, Argentina, and Uruguay, classification serves to segregate carcasses on the basis of both yield and quality.

Meat Standards Australia (MSA) has taken a slightly different approach than other countries in developing a new beef quality grading system. Instead of grading beef carcasses, the MSA grading system is designed for grading individual cuts and does so by taking into consideration not only the physical characteristics of the carcass, but also factors that affect palatability before slaughter and after the carcass has been fabricated into cuts (Meat and Livestock Australia, 2003). This system was developed to predict palatability by conducting extensive consumer taste tests and has resulted in a palatability score which is a combination of consumer ratings (Meat and Livestock Australia, 2003). This palatability score is then predicted for individual cuts using production, carcass, aging, and suggested cooking method information to assign a final grade (Meat and Livestock Australia, 2003). One large difference between this system and other systems is that a cut may actually receive more than one grade. For example, a strip loin may receive a 3-star grade if it is aged for 14 d, or it may receive a 4-star grade if it is aged for 21 d. This system also employs the use of process control via critical control points in that there are a few qualifications that cattle must meet to be eligible to receive MSA grades in order to help improve the palatability of the product graded by MSA. For example, cattle must be transported directly to the slaughterhouse and not mixed with other cattle in the holding area; carcasses must meet a minimum fat covering specification, a maximum ultimate pH specification, and a maximum ossification score (Meat and Livestock Australia, 2003). Measurements or information used to predict the palatability score include *Bos indicus* percentage of the animal, hump height, gender, carcass weight, the method used to hang the carcass, USDA marbling score, fat thickness, ultimate pH, and the number of days the cuts are aged (Meat and Livestock Australia, 2003).

Advantages and disadvantages of beef grading systems

Purchas et al. (1999), in a simulation study of potential payment systems for beef carcasses, demonstrated that there is a major advantage to using a grading system that allows for prices to be paid according to yield on a continuous basis rather than by steps or classes. This is because, even within a step or a class, there are differences in value; by pricing all carcasses the same within a step or class these actual differences in value are not transmitted. The yield grading systems used in the U.S., Canada, South Korea, and Japan are developed in a manner that would allow for a continuous prediction of meat yield; however, in current practice, this is not achieved, most likely because of the time required to apply the grades in a continuous manner.

The grading systems used in the EU, Brazil, Argentina, and Uruguay do not allow for the computation of a continuous estimate of yield or quality. This makes it difficult to establish a value-based marketing system because there are a very large number of possible grades that a carcass can receive and it is a challenge for packing plants to establish prices for each of the grades, especially for grades that few carcasses receive.

The MSA grading system is clearly the most consumer oriented and quality driven of all of the grading systems discussed. While the MSA grading system encourages the implementation of technologies to improve the quality of beef, because cuts can be "upgraded" through their use, a drawback is that it may be difficult to determine the actual value of a carcass before it is fabricated. This is because not all cuts receive the same grade and, for some cuts, multiple grades may exist depending on the length of time the cuts are aged or how they are cooked.

In all the systems discussed, there is a great dependence on trained personnel to carry out beef grading. Production and processing practices, as well as consumer preferences for beef, have and will continue to change over time, thus it is important for beef grading systems to evolve to meet the needs of all. There has been great interest and considerable research devoted to the development of instrumentation for use in beef grading systems. The objectivity of instrumentation could allow for a more standardized method of grade application than is achieved by using subjective scores and grades assigned by human graders. Objective grading is viewed as advantageous by producers, who perceive that the application of subjective grades is inconsistent (Cross and Whittaker, 1992). Instrumentation also can help to provide grading information at the current speeds of beef processing facilities. Recently, USDA approved the use of a video image analysis system to augment the application of USDA yield grades as a way to improve grade placement accuracy and provide a more continuous measurement of yield. Further development and implementation of instrumentation into beef grading systems could help meet the needs of the producer, processor, and consumer.

CHAPTER III

Video Image Analysis as a Potential Grading System for Uruguayan Beef Carcasses

INTRODUCTION

The Uruguayan beef industry currently uses a beef carcass classification system that is maintained by the Uruguay National Institute of Meat, but applied by packing plant personnel, to classify carcasses according to gender, estimated chronological age (dentition), and subjective scores for muscle conformation and fatness. A recent audit of beef carcass characteristics in Uruguay indicated that over 50% of carcasses are of the same chronological age (eight permanent incisors), 80% receive the same muscle conformation score, and over 80% receive the same fatness score (Uruguay National Institute of Agricultural Research, 2003). This suggests the need for the Uruguayan beef industry to develop a more discriminatory method of sorting carcasses into more uniform marketing groups that differ in cutability, palatability, and value.

Video image analysis (VIA) systems have been developed and tested in several countries to predict meat yield percentage using output data resulting from the processing of digital images of either the entire side of a hot beef carcass, or the cross-section of the rib interface after a beef carcass has been chilled, or by a combination of data from both digital images (Jones et al., 1995; Borggaard et al., 1996; Cannell et al., 2002). Vote et al. (2003) reported that carcasses could be more uniformly grouped within USDA grades according to differences in tenderness with the use of a commercialized chilled carcass VIA system (Computer Vision System equipped with a BeefCam module; CVS BeefCam) at operational speeds. The present study was conducted in two phases to evaluate the effectiveness of: 1) the VIAscan Beef Carcass System (hot carcass system) and the CVS BeefCam (chilled carcass system), used independently or in combination, to predict Uruguayan beef carcass fabrication yields; and 2) the CVS BeefCam to segregate Uruguayan beef carcasses into groups that differ in the Warner-Bratzler shear force values of their longissimus steaks.

MATERIALS AND METHODS

Meat Yield Phase

Carcass Selection and Video Image Collection. Beef carcasses were selected over a 5-wk period at a commercial Uruguayan packing plant (NIREA, San Jacinto, Uruguay) to fill a selection matrix that included gender (steers and females), fat thickness (< 0.6 cm and ≥ 0.6 cm), and carcass weight within gender (< 230 kg and ≥ 230 kg for steers; < 200 kg and ≥ 200 kg for females). Over one-third of the carcasses selected originated from mature cows. Colorado State University (CSU) personnel selected carcasses during the slaughter process after hot carcass weights were obtained, but before carcasses passed through the VIAscan Beef Carcass System (BCS; VIAscan Quality Assessment, Beenleigh, Queensland, Australia). The BCS collected an image of the outside surface of each carcass side as it passed through a cabinet. This image was then processed by proprietary software, in real-time, to produce output variables for carcass dimension (area, linear, and shape measurements), ratios of linear measurements, and color of the carcass surface. Carcasses then passed through a carcass wash before being moved into the chilling cooler where they were chilled overnight for 15 to 23 h, except for carcasses selected on Fridays (third and fourth weeks) in which case carcasses were chilled for 63 to 71 h, and on Saturdays (first and second weeks) in which carcasses were chilled for 39 to 47 h.

After chilling, carcasses were transferred from the chilling cooler to a holding rail for further data collection (recording of carcass identification number, hot carcass side weights, dentition, Uruguay National Institute of Meat --INAC-- muscle conformation score, INAC fat score, and gender from the plant carcass tag). Carcass sides were randomly chosen for fabrication unless a side had excessive trimming or other slaughter defects that would dramatically affect the weight of an individual subprimal cut or major muscle, in which case the side with the fewest dressing defects was designated for fabrication. Carcass sides designated for fabrication were ribbed at the 10th/11th rib interface and any bone dust created during ribbing was removed from the exposed surface. Shortly following ribbing (approximately one min), images were collected from the 10th/11th rib interface using a CVS equipped with a BeefCam module (CVS BeefCam; RMS Research Management Systems, Fort Collins, CO) and plant bar-coded tags were scanned to match images to the appropriate carcass identification number. Dark-cutting carcasses (≥ one-third grade discount) were identified by visual appraisal and USDA quality and yield grade factors were assigned to each carcass by CSU personnel. At approximately 50 min post-ribbing, a second CVS BeefCam image of the 10th/11th rib interface was collected. Images were processed, in real-time, using proprietary software designed to analyze the cross-section of the 12th/13th rib interface. However, the inconsistent presence, size, and shape of the trapezius muscle at the 10th/11th rib interface made accurate measurements of fat thickness difficult using existing software. Therefore, images were saved so that they could be re-processed later using optimum software configurations to yield output variables for longissimus muscle (LM) color and area (LMA), fat color, marbling, and fat thickness. Also, two alternative output variables, the ratio of the number of pixels considered to be fat, to the total number of pixels in the 10th/11th rib interface (percent fat) and the total number of pixels considered to be lean in the 10th/11th rib interface (total lean) were developed from the images. Output variables from these reprocessed images were used in data analyses.

Carcass Fabrication and Saleable Meat Yield Calculations. Trained plant personnel first fabricated quarters into untrimmed boneless subprimals (rough cuts). These untrimmed boneless subprimals, along with the bone generated during fabrication, were weighed in order to calculate a side gross weight (summation of all untrimmed subprimals and bone). Subprimals, muscle groups, or individual muscles were then trimmed sequentially to up to three fat trim specifications, with all parts being weighed and retained at each stage of trimming. Fat trim specifications included: commodity trimmed (COMM; maximum fat thickness of one cm), closely trimmed (CLOSE; maximum fat thickness of 0.5 cm), and very closely trimmed (VCLOSE; trimmed free of fat; peeled or denuded) cuts. After cuts were trimmed to the VCLOSE fat thickness, some cuts were further separated and trimmed free of fat [extra closely trimmed (XCLOSE)]. After a carcass side was completely trimmed free of fat, lean trimmings generated during the fabrication process of an entire side were combined for subsequent percent fat analysis. Lean trimmings were ground twice using a grinder with a 1.27-cm plate and sub-sampled in duplicate (250 g each). Each sub-sample was homogenized with a food processor and analyzed for fat percentage using an Anyl Ray (Frans Vermee GmbH, Remagen, Germany). The Anyl Ray (Frans Vermee GmbH, Remagen, Germany) was chosen as the method of determining fat percentages because it was the only technology available for such purpose at the commercial packing plant. The results from the duplicate samples were averaged to obtain a single estimate of the fat percentage of the lean trimmings.

Total product weight recovered from each carcass side was computed for each of four cutability endpoints. Total product recovery weights at each cutability endpoint were divided by the carcass side gross weight to obtain a weight recovery percentage at each endpoint. Side gross weights were chosen to determine the percent weight recovery because they were not influenced by the variation in trolley weights that was observed in measuring chilled carcass side weights. Only carcass sides with a fabrication weight recovery percentage between 99.5 and 100.5%, at all of the four cutability endpoints, were used in data analyses.

Saleable meat yields were calculated as a percentage of the carcass side gross weight for each of four cutability endpoints (COMM, CLOSE, VCLOSE, and XCLOSE). A listing of the subprimals, muscle groups, or individual muscles with the fat trim specification used in the calculation of each cutability endpoint is provided in Table 3.1. For the COMM, CLOSE, and VCLOSE cutability endpoints, the saleable meat yields were comprised of only the weights of subprimals and whole muscles; the weight of lean trimmings was not included. For the XCLOSE cutability endpoint, the weight of saleable meat included the weight of all trimmings generated from a carcass side, which was adjusted to zero percent fat (100 percent minus the fat percentage times the weight of all lean trimmings). Fat trim percentage was calculated by dividing the weight of waste fat generated during the production of VCLOSE saleable meat by the carcass side gross weight. Bone percentage was calculated by dividing the weight of all bone and cartilage by the carcass side gross weight. Additionally, a lean to bone ratio was calculated by dividing the XCLOSE saleable meat weight (including the weight of lean trimmings adjusted to zero percent fat) by the weight of all bone and cartilage.

Statistical Analyses. Principal component, regression, and descriptive analyses were all performed using SAS (SAS Inst. Inc., Cary, NC). Descriptive statistics for selected carcass traits, USDA yield grade factors, and fabrication yield percentages were computed for carcasses included in the meat yield phase. In applying the INAC beef classification system, the first step is to classify a steer or female carcass as such (classification of intact males will not be discussed). Secondly, a carcass is classified to one of four dentition classes for steers (< two, two to four, six, and > six permanent incisors) or to one of three dentition classes for females (< four, six, and > six permanent incisors). Thirdly, a carcass receives a single subjective muscle conformation score with the number of possible scores depending on the dentition classification for both steers and females. Lastly, a carcass receives a single subjective fat covering score with the number of possible scores depending on the dentition classification and the muscle conformation scores for both steers and females. In total, a steer carcass could receive one of 85 possible final INAC grades and a female carcass could receive one of 59 possible final INAC grades. In this phase of the present study, carcasses from 38 different INAC grades (steer and female carcasses combined) were represented. This type of classification system does not provide an estimate of fabrication yield, but operates on the premise that carcasses will be more uniform with respect to fabrication yield within a class than if no classification system is used. In order to compare the effectiveness of the current INAC beef classification system to other methods of predicting fabrication yields, the mean fabrication yield of each final INAC grade was used as the predicted fabrication yield for that final INAC grade.

Simple linear regression equations were developed to predict actual fabrication yields using INAC grades and USDA yield grades calculated to the nearest 0.1 (with kidney, pelvic, and heart fat standardized at 0.5%). Multiple linear regression models were developed using stepwise (α for entry was set at 0.15 and α for exit was set at 0.16) model selection procedures to predict actual fabrication yields from hot carcass weight (HCW) and only one of two subsets of CVS BeefCam output variables: (a) either the output variables, percent fat and total lean, or (b) measurements of LMA, marbling, and fat thickness.

Principal component analyses were conducted on subsets of dimensional and color measurements to reduce the number of independent BCS output variables and to avoid problems with multicollinearity before performing regression analyses. Stepwise (α for entry was set at 0.15 and α for exit was set at 0.16) model selection procedures were used to identify which sets of principal components of BCS output variables were not useful for predicting actual fabrication yields. These sets of principal components were removed from the available pool of BCS output variables and stepwise (α for entry was set at 0.15 and α for exit was set at 0.16) model selection procedures were used again to develop models for predicting fabrication yields - - this time allowing HCW to be included as an independent variable. The principal component scores that entered regression equations along with the percentage of standardized variance accounted for by each principal component score are provided in Table 3.2. Additionally, multiple linear regression equations were developed using stepwise (α for entry was set at 0.15 and α for exit was set at 0.16) model selection procedures from CVS BeefCam and BCS output variables to predict actual fabrication yields by first narrowing the pool of available BCS output variables and allowing only one of the two subsets of CVS BeefCam output variables to be included in the final model.

Tenderness Phase

Carcass Selection and Warner-Bratzler Shear Force Determination. Carcasses selected for inclusion in the meat yield phase also were included in the tenderness phase. Additional carcasses were randomly selected after passing the hot carcass scale to be included in the tenderness trial (in total, N = 345). Chilling, grading and CVS BeefCam imaging procedures were conducted as was described in the meat yield phase. When the fabrication of a carcass side was completed, a 2.54-cm-thick steak of the longissimus muscle was removed, vacuum-packaged, and aged at 2°C until 14d postmortem, at which time they were frozen (-20°C) and stored for subsequent shear force analysis. Frozen steaks were thawed for 24 h at 4°C before being cooked in a water bath (80°C) until reaching an internal temperature of 70°C as determined by use of a thermocouple (type E, Barnant 115, model 600-2810, Barnant Co., Barrington, IL). Cooked steaks were then chilled for 3 to 4 h at 4°C before removing six cores (1.27 cm) parallel to the muscle fiber orientation. A single, peak shear force measurement was obtained for each core using a Warner-Bratzler shear force (WBSF) machine (G-R Manufacturing Co., Manhattan, KS).

Individual-core peak shear force values were averaged to assign a mean peak WBSF value to each steak.

Statistical Analyses. Correlation, regression, and ANOVA analyses as well as descriptive statistics were all performed using SAS (SAS Inst. Inc., Cary, NC). Descriptive statistics for selected carcass traits, CVS BeefCam output variables, USDA quality grade factors, and WBSF values were computed for carcasses included in the tenderness phase. Correlation coefficients were calculated between CVS BeefCam measurements for lean color and WBSF values for all carcasses sampled (N = 345) at both image collection times (shortly after ribbing and after approximately 50 min of bloom). Also, correlation coefficients were calculated between WBSF values and the lean color measurements of only those carcasses not considered to be dark-cutters by visual appraisal (n = 285) at both image collection times.

Any of several methods (visual appraisal, measurement of ultimate pH value, or use of a CVS BeefCam lean color threshold) could be used to identify dark-cutting carcasses and exclude them from being grouped with carcasses with normal lean color, thus dark-cutting carcasses assessed by visual appraisal were excluded from the following segregation analyses. Carcasses were segregated into four groups according to INAC grades for gender and dentition (young steers = steers with ≤ four permanent incisors; mature steers = steers with ≥ six permanent incisors; heifers = females with ≤ four permanent incisors; mature cows = females ≥ six permanent incisors). Independent of the INAC grade classifications, carcasses were segregated into three groups based on USDA quality grades (Group 1 = carcasses that received Prime, Choice, or Select grades; Group 2 = carcasses that received the Standard grade; Group 3 = carcasses that received

Commercial, Utility, or Cutter grades). Mean values for WBSF, LMA, lean L*, lean a*, lean b*, fat L*, fat a*, fat b*, and USDA marbling score of groups were compared for each of the classification methods using ANOVA and separated using the Tukey-Kramer method.

To determine if CVS BeefCam output variables could aid INAC grades in sorting carcasses into groups that yield steaks differing in tenderness, the following approach was used. First, data from young steer, mature steer, and heifer carcasses were combined because they yielded steaks with similar WBSF values, while the data from mature cow carcasses were kept separate to ensure that the effects of segregation by CVS BeefCam output variables were not due only to separating mature cow carcasses from steer and heifer carcasses. Secondly, carcasses were classified within the two data subsets into three groups based on each CVS BeefCam output variable (Low = the lowest one-third of carcasses for each CVS BeefCam output variable; Medium = the middle one-third of carcasses for each CVS BeefCam output variable; High = the highest one-third of carcasses for each CVS BeefCam output variable). Group means were analyzed using ANOVA and separated using the Tukey-Kramer method.

RESULTS AND DISCUSSION

Meat Yield Phase

Numbers of carcass sides arrayed by gender, fat thickness, carcass weight, and INAC muscle conformation score included in the yield data analyses are displayed in Table 3.3. An attempt was made to select equal numbers of heavy and light muscled carcasses according to INAC muscle conformation scores (N as heavy muscled, and A, C, and U as light muscled, carcasses); however, due to the carcass population typically encountered at the commercial processing facility, the muscle conformation score A was represented in greater numbers than any of the other muscle conformation scores (Table 3.3).

Descriptive statistics for carcass traits and fabrication yields of carcasses included in the meat yield phase are presented in Table 3.4. In Uruguayan beef packing plants it is customary practice to remove or trim large fat depots such as kidney and pelvic fat, cod or udder fat, and fat over the brisket, prior to collecting a HCW. The practice of hot-fat trimming has been shown to reduce the amount of variation among carcasses in fat trim, as a percentage of carcass side weight (Savell et al., 1989; Williams et al., 1989; Ahmed et al., 1992), as the amount of fat removed from fatter carcasses was larger than the amount of fat removed from lean carcasses in relation to carcass weight. Even with the practice of removing large fat depots, fat trim as a percentage of carcass side gross weight was the most variable trait among the different calculated fabrication yields (Table 3.4). Mean values for lean to bone ratio and bone weight as a percentage of carcass side gross weight indicated that sampled carcasses were thinly muscled (Table 3.4). Bone percentages observed in this study were comparable to those of Apple et al. (1999) who reported values of 17 to 32% for cull beef cow carcasses that exhibited a large range in body condition scores, but were considerably higher than bone percentages typically encountered in the U.S. fed beef population (Griffin et al., 1992). This could be attributed to a combination of factors; cattle slaughtered in Uruguay are from a predominately British genetic base, finished on grass pastures, and proportionally high in percentage of mature cow carcasses in the slaughter population (Uruguay National

Institute of Agricultural Research, 2003). Carcasses were most variable for adjusted fat thickness (CV = 66.3), while HCW, LMA, USDA preliminary yield grade, and USDA yield grade were similar and less variable (CV = 18.3, 16.9, 19.1, and 22.8, respectively; Table 3.4).

Presented in Table 3.5 are R^2 and root mean square error (RMSE) values for regression equations in which INAC grade, USDA yield grade, CVS BeefCam, BCS, or CVS BeefCam plus BCS output variables were used to predict saleable meat yields. For all methods of predicting saleable meat yield except for INAC grades, the proportion of explained variation increased as the fat trim level decreased, which agreed with analyses reported by Cannell et al. (1999). Sixteen of the 38 INAC grades contained only one carcass; thus, the predicted fabrication yield for those grades was equal to the actual fabrication yield and therefore the usefulness of the INAC beef classification system was likely to be overstated. Overall, predictions of saleable meat yields by INAC grades were low, even though the predicted saleable meat yields for sixteen of the final INAC grades were equal to the actual saleable meat yields (Table 3.5). Coefficients of determination for predictions of fat trim percentage and bone percentage by INAC grades were higher than values for the prediction of saleable meat yield percentages (Table 3.5).

The USDA yield grade calculated to the nearest 0.1 accounted for substantially more variation in VCLOSE and XCLOSE saleable meat yields than did INAC grades, even though kidney, pelvic, and heart fat percentages were standardized at 0.5% and LMA was measured at the 10th/11th rib interface (Table 3.5). The proportions of variation in saleable meat yield percentages explained by USDA yield grades calculated to the nearest 0.1 were somewhat lower than has previously been reported. Steiner et al. (2003)

reported that USDA yield grades applied by on-line graders accounted for 55% of the variation in subprimal yield and USDA yield grades calculated to the nearest 0.1 of a grade by expert USDA graders accounted for 71% of the variation in subprimal yield. Similar results were reported by Cannell et al. (1999) who found that USDA yield grades applied by on-line graders accounted for 37, 54, and 54%, respectively, and USDA yield grades applied by expert graders and calculated to the tenth of a grade accounted for 51, 74, and 74%, respectively, of the variation in commodity-trimmed, closely trimmed, and very closely trimmed beef carcass yield percentages.

The amount of variation explained by the USDA yield grades in the present study was likely lower because the mean adjusted fat thickness for the sample carcasses was much less than those reported by Cannell et al. (1999) and Steiner et al. (2003) (0.8 vs. 1.4 and 1.3 cm, respectively). O'Mara et al. (1998) reported that carcass kidney, pelvic, and heart fat adjustment was an important predictor of the total fat percentage of mature cows. Because kidney, pelvic, and heart fat was removed from the carcasses in this study prior to fabrication, and over one-third of the carcasses in this study were from cattle of greater maturity, this may also have limited the usefulness of the USDA yield grades to predict fabrication yields. Also, in this sample of beef carcasses, HCW explained essentially none of the observed variation in saleable meat yield percentages (data not presented in tabular form); Cannell et al. (1999; 2002) also reported that HCW was not correlated to beef carcass yield percentages. The USDA yield grade equation calculated to the nearest 0.1 was not very effective for predicting bone percentage or lean to bone ratio. This was not unexpected because the USDA yield grade equation was developed to predict carcass yield of boneless, closely trimmed subprimals (USDA, 1997).

The best equation to predict saleable meat yield percentages using CVS BeefCam output used only one variable, percent fat, which accounted for 41, 45, 55, and 57% of the observed variability in COMM, CLOSE, VCLOSE, and XCLOSE saleable meat yield percentages, respectively (Table 3.5). In previous research, similar VIA output variables were found to be highly related to the 9-10-11th rib composition (Cross et al., 1983), carcass primal lean and fat percentages (Wassenberg et al., 1986) and beef carcass retail product yield (Shackelford et al., 1998). Cannell et al. (1999) reported that the VIAscan chilled carcass system accounted for 46, 64 and 68% of the variation in commodity-trimmed, closely trimmed, and very closely trimmed yield percentages, respectively. The best equation using the CVS chilled carcass system measurements reported by Cannell et al. (2002) included midpoint fat, LMA, and HCW and accounted for 60% of the variation in carcass yield. The slightly lower R^2 values in the present study for predicting saleable meat yield percentages compared to results of other studies may be due to the reduced average fat thickness of sampled carcasses, or could also be due to the amount of fat that was trimmed from carcasses before crossing the hot carcass scales.

Output variables from a Computer Vision System equipped with a BeefCam module explained a higher proportion of variation in fat trim percentage than variation in saleable meat yield percentages (Table 3.6). Values for R^2 were higher for the prediction of carcass side bone percentage (Table 3.7) than for the prediction of lean to bone ratio (Table 3.8; 0.51 vs. 0.33, respectively) even though models using CVS BeefCam output variables were similar.

Simple correlation coefficients between LMA with COMM, CLOSE, VCLOSE, or XCLOSE saleable meat yield percentages were 0.33, 0.35, 0.30, and 0.27, respectively, in the present study (data not presented in tabular form) whereas simple correlation values of 0.59 and 0.63 between LMA and closely trimmed yield percentages were reported by Cannell et al. (1999) and Cannell et al. (2002), respectively. The disparity between the present study and the Cannell et al. (1999; 2002) studies may be due to the breed consistency of the Uruguayan cattle or due to the inclusion of more mature animals in this study to reflect the normal slaughter consist of a typical Uruguayan packing plant.

The best equation using BCS output to predict saleable meat yield percentages included variables for the ratio of the length of the carcass from the hindshank to the elbow to the length of the carcass from the hindshank to a point anterior to the foreshank, plus principal components for carcass color and for the shape of the round. Principal components for carcass color collectively accounted for the majority of the explained variation in saleable meat yields while a principal component for round shape accounted for approximately 6% and the dimensional ratio accounted for approximately 3% of the explained variation in saleable meat yields. This equation resulted in R^2 values of 0.49, 0.52, 0.58, and 0.59 for COMM, CLOSE, VCLOSE, and XCLOSE saleable meat yield percentages, respectively (Table 3.5). These R^2 values were larger than those presented by Cannell et al. (1999) who found that the VIAscan hot carcass system wholesale yield prediction resulted in R^2 values of 0.19, 0.32 and 0.38 for commodity-trimmed, closely trimmed, and very closely trimmed yield percentages. Jones et al. (1995), in a study of the effectiveness of the VIAscan hot carcass system for predicting the yield of Canadian carcasses, reported R^2 values of 0.57 and 0.42 for saleable meat yield (6 mm of maximum fat thickness) and subprimal cut yield (6 mm of maximum fat thickness), respectively.

Use of BCS output variables to predict percentages of fat trim (Table 3.6) or bone (Table 3.7) as well as the ratio of lean to bone (Table 3.8) resulted in higher R^2 values than did the use of INAC grades, USDA yield grade calculated to the nearest 0.1, or CVS BeefCam output variables. For the BCS prediction of fat trim percentage, principal components for carcass color collectively explained over 70% of the variation, while principal components for round and loin shape, carcass length ratios, carcass width, and carcass size, each accounted for approximately 1% of the variation (data not presented in tabular form). For the BCS prediction of bone percentage, principal components of round shape collectively accounted for over 35% of the variation, while principal components for carcass color collectively accounted for over 20% of the variation, with HCW and carcass width ratios also accounting for approximately 1% of the variation (data not presented in tabular form). For the BCS prediction of the ratio of lean to bone, principal components of round shape collectively accounted for over 30% of the variation and principal components of carcass color, carcass width, and a ratio of carcass length each accounted for approximately 1% of the variation (data not presented in tabular form). Thus, it appeared that the BCS was more effective at explaining differences in muscling among carcasses by measuring the shape of the round than the CVS BeefCam was by measuring the LMA.

Combining the CVS BeefCam and BCS output variables in regression equations, as would occur in a dual-component approach, increased the amount of variation explained in saleable meat yield percentages at each cutability endpoint compared to using either instrument individually (Table 3.5). These results were consistent with reports by Jones et al. (1995) and Cannell et al. (1999; 2002) in which it was reported that

R^2 values improved to 0.64 to 0.69 for those three studies, by using both hot and chilled carcass VIA systems to predict beef carcass yield. Coefficients of determination for predicting fat trim percentage (Table 3.6) and bone percentage (Table 3.7) were not increased appreciably by combining output data from the CVS BeefCam and BCS compared to using output data from the BCS only. The percentage of variation explained in the ratio of lean to bone was increased by eight percentage points when BCS and CVS BeefCam output variables were combined over using only BCS output variables (Table 3.8).

The current INAC beef carcass classification system presents a challenge for Uruguayan packers relative to implementing a value-based pricing system because prices would need to be different among each INAC grade in order to send a price signal to producers. Because so few carcasses receive certain INAC grades, it is difficult for the packer to estimate what the actual fabrication yield of a carcass of a particular grade might be, thus it is difficult for them to establish prices for different grades. Purchas et al. (1999) reported that the advantages of using a carcass payment system that uses a continuous prediction of yield, instead of a step or class system, could be as great as, or greater than, improving the accuracy of yield prediction. The results from this phase of the present study indicate that the prediction of saleable meat yield percentages from Uruguayan beef carcasses by use of the BCS or CVS BeefCam are similar to, or slightly better than, the use of USDA yield grade calculated to the nearest 0.1 and are much greater than predictions based on INAC grades. A further improvement in fabrication yield prediction could be obtained by use of a dual-component VIA system. Whichever method of VIA prediction of fabrication yield is used, a single predicted value of fabrication yield for every carcass would remove an impediment to the implementation of a value-based pricing system. Additionally, a VIA method of predicting carcass yield has the advantage over the current INAC classification system in that estimates would be produced by an instrument rather than by packing plant personnel, which would appeal to cattle producers.

Tenderness Phase

Descriptive statistics for carcass traits of the sample population used in the tenderness phase are presented in Table 3.9. Carcasses included in the tenderness phase were diverse in terms of maturity, marbling, fat color, and WBSF values. The majority of the carcasses sampled would have received USDA quality grades of Select, Standard, or Utility (data not presented in tabular form). Of the carcasses sampled, 17.4% were considered to be dark-cutters by visual appraisal, which was similar to the results of the Uruguayan Beef Quality Audit-2002 where it was reported that dark-cutters occur at a frequency of 18.8% (Uruguay National Institute of Agricultural Research, 2003). Murray (1989) reported that the visual assessment of dark-cutting beef is affected by the length of time between ribbing and LM color evaluation and, also, by the number of hours postmortem at which the color evaluation is performed. In that study, the frequency of dark-cutting beef was higher for carcasses that were evaluated 15 to 18 h postmortem and within an hour of ribbing than it was for carcasses evaluated at 22 to 26 h postmortem and within an hour of ribbing (Murray, 1989). The vast majority of carcasses evaluated in this study were visually assessed within one hour of ribbing, and over 80% were assessed at less than 23 h postmortem. It is possible then that carcasses were classified as dark-cutters, when in fact they were not, because some carcasses may not have yet reached their ultimate muscle pH.

Correlation coefficients between WBSF values and CVS BeefCam output variables obtained shortly after ribbing and approximately 50 min after ribbing for all carcasses and for carcasses not considered to be dark-cutters by visual appraisal are presented in Table 3.10. Using all carcasses, correlation coefficients between WBSF and CVS BeefCam output variables obtained at both image collection times were similar. For images collected shortly after ribbing, exclusion of dark-cutting carcasses improved correlations between lean L* and lean a* with WBSF values. When dark-cutters were excluded, all lean color output variables from images collected 50 min after ribbing were more highly correlated with WBSF values than were those collected shortly after ribbing. Vote et al. (2003) reported simple correlation values of -0.05 to -0.31, -0.13 to -0.40, and -0.12 to -0.38 between CVS BeefCam lean L*, lean a*, and lean b*, respectively, and WBSF values, for the four experiments in their study. Wulf and Wise (1999) reported that lean b* increases more rapidly during the first three min of bloom time than does lean L* or lean a*, suggesting that even the slightest amount of variation in the timing of color measurement shortly after ribbing can translate into a large amount of variation in lean b* values. This most likely explains why the correlation coefficient between lean b* and WBSF values was lower for the images collected shortly after ribbing than for the images collected approximately 50 min after ribbing, and further suggests that a minimum length of bloom time should be required, before imaging, to maximize the relationship between lean color measurements and WBSF values. Correlation coefficients between fat color measurements, marbling and adjusted LMA (cm^2 per kg of

HCW) remained comparable when dark-cutters were included vs. excluded from the data set (Table 3.10).

Figure 3.1 displays the relationship between lean color (obtained approximately 50 min after ribbing) and WBSF values for carcasses with normal-colored lean, and with one-third grade, two-thirds grade, or full grade dark-cutter discounts (as assessed by visual appraisal). Information in this figure confirms that sorting carcasses using lean color measurements without first identifying carcasses as dark-cutters would be ineffective, if WBSF values are the sole measure of sorting effectiveness. Wulf et al. (2002) reported that cooked beef palatability was lower and WBSF values were higher and more variable for steaks from dark-cutting carcasses than for steaks from carcasses with normal-colored lean. In this study, the mean WBSF values were 4.0, 3.5, and 2.9 and WBSF value SD were 1.7, 0.8, and 1.1 for carcasses with one-third grade, two-thirds grade, and full grade dark-cutter discounts (as assessed by visual appraisal), respectively (data not presented in tabular form). Wulf et al. (1997) reported that lean L*, lean a*, and lean b* were moderately correlated with LM ultimate pH values. If the product value of CVS BeefCam lean L*, lean a*, and lean b* indirectly measures ultimate pH, then results of this study are in agreement with the concept that there is a region of ultimate pH that results in highly variable WBSF values (Wulf et al., 2002) while carcasses with high ultimate pH values will have low WBSF values (Bouton et al., 1973; Yu and Lee, 1986). Figure 3.1 also reveals that a CVS BeefCam lean L*, lean a*, and lean b* product value (obtained after an approximate bloom time of 50 min) threshold could be established for use in classifying carcasses as dark-cutters.

Presented in Table 3.11 are carcass characteristics and WBSF values when carcasses (excluding dark-cutters) were classified into four groups using INAC grades (i.e., based upon gender and dentition). Steer carcasses had larger ($P < 0.05$) LMA than female carcasses. Heifer carcasses had significantly brighter (indicated by lean L*) and redder (indicated by lean a*) LM lean color than young steer carcasses, which had brighter ($P < 0.05$) LM lean color than mature steer or cow carcasses (Table 3.11). Heifer carcasses also had the whitest colored fat and lowest lean maturity scores of the four groups (Table 3.11). As expected, steaks from mature cow carcasses had the highest ($P < 0.05$) WBSF values, and mature cow carcasses received the highest ($P < 0.05$) skeletal and lean maturity scores and had the most ($P < 0.05$) yellow colored fat of all the groups (Table 3.11). The Uruguayan National Beef Quality Audit-2002 (Uruguay National Institute of Agricultural Research, 2003) revealed that 76.1, 18.3, and 4.6% of the carcasses were steers, mature cows, and heifers, respectively. These results suggest that increasing the percentage of heifers slaughtered in Uruguay could greatly improve the tenderness and desirability of lean and fat color of the beef that is currently produced in Uruguay.

Carcass characteristics and WBSF values when carcasses (excluding dark-cutters) were classified into three groups using USDA quality grades are presented in Table 3.12. The USDA quality grade groups differed greatly in WBSF values. Among youthful carcasses (Groups 1 and 2), marbling score, lean L*, lean a*, lean b*, fat L*, and fat b* were greater ($P < 0.05$) for Group 1 than for Group 2. Lean maturity scores for carcasses in quality grade Group 2 corresponded with those characteristics of B-maturity lean and were greater ($P < 0.05$) than lean maturity scores for Group 1 which corresponded with those characteristics of A-maturity lean. Carcasses in quality grade Group 3 had the highest ($P < 0.05$) fat b* values, skeletal and lean maturity scores, and WBSF values.

The results of using CVS BeefCam output variables to segregate carcasses into classes are presented in Table 3.13 for steer and heifer carcasses (combined) and for mature cow carcasses. Adjusted LMA (cm^2/kg of HCW) was not useful ($P > 0.05$) for sorting steer and heifer, or mature cow carcasses into groups that differed in WBSF values. The Low lean L* group generated the toughest ($P < 0.05$) steaks of the three groups for mature cow carcasses and the Low lean L* group generated tougher ($P < 0.05$) steaks than steaks from the Medium group for steer and heifer carcasses. Wulf and Page (2000) reported that carcasses generating tougher steaks could be identified with a low lean L* threshold. In the present study, lean a* was effective ($P < 0.05$) for identifying a group of carcasses that yielded steaks with higher WBSF values for both mature cow carcasses and steer and heifer carcasses. Carcasses in the Low lean b* group for both mature cow and steer and heifer carcasses generated tougher ($P < 0.05$) steaks than did carcasses in the High lean b* group. These results agree with the results of Vote et al. (2003) who reported that either CVS BeefCam lean a* or lean b*, and with the results of Wulf and Page (2000), in the case of lean b*, could be used to identify a group of carcasses that would yield steaks with higher WBSF values. Mature cow carcasses in the High fat L* group yielded steaks that were more tender ($P < 0.05$) than those from carcasses in the Low fat L* group. This was in agreement with Hodgson et al. (1992) and Hilton et al. (1998) who reported fat color to be an important predictor of palatability of steaks from mature cow carcasses and suggested that fat color be used in classifying mature carcasses with respect to palatability of their cuts. Fat L* was ineffective (P >

0.05) for segregating steer and heifer carcasses according to WBSF values of their steaks. Fat a*, fat b*, and CVS BeefCam marbling were not effective ($P < 0.05$) in segregating carcasses of steers and heifers or mature cows into groups which yielded steaks that differed in tenderness.

The CVS BeefCam output variable for marbling was not ($P > 0.05$) able to segregate steer and heifer carcasses into groups that differed in WBSF values, although carcasses in the USDA quality grade Group 1 yielded steaks that had lower WBSF values than did carcasses in Group 2. This, along with the results of segregating steer and heifer carcasses according to lean color output variables, indicate that lean maturity, but also skeletal maturity, were useful for segregating carcasses according to differences in WBSF values of their steaks, among USDA quality grade groups 1 and 2. A beef carcass quality grading system using CVS BeefCam could be established in which steer or heifer carcasses that meet a minimum lean a* value could be grouped together as a premium product, steer or heifer carcasses with low lean a* values could be grouped with mature cow carcasses that meet a minimum lean a* value as a commodity product, and mature cow carcasses with low lean a* values could be grouped together and marketed at a discount or directed to further processing.

IMPLICATIONS

Use of video image analysis to predict beef carcass fabrication yields could improve the accuracy and reduce the subjectivity in comparison to use of current Uruguay National Institute of Meat grades. Use of video image analysis to sort carcasses according to lean color would allow for the marketing of more consistent beef products with respect to tenderness. This would help facilitate the initiation of a value-based marketing system for the Uruguayan beef industry.

Table 3.1 List of boneless subprimals, muscle groups, or individual muscles, with fat trim specifications, that were used in the calculation of saleable meat yield percentages for cutability endpoints[a]

Cutability endpoint			
COMM	CLOSE	VCLOSE	XCLOSE[b]
VCLOSE-Cutaneous trunci	VCLOSE-Cutaneous trunci	VCLOSE-Cutaneous trunci	VCLOSE-Cutaneous trunci
CLOSE-short plate	CLOSE-short plate	VCLOSE-short plate	VCLOSE-short plate
VCLOSE-outside skirt	VCLOSE-outside skirt	VCLOSE-outside skirt	VCLOSE-outside skirt
CLOSE-short rib (forequarter; 10 ribs)	CLOSE-short rib (forequarter; 10 ribs)	VCLOSE-short rib (forequarter; 10 ribs)	VCLOSE-short rib (forequarter; 10 ribs)
CLOSE-neck meat	CLOSE-neck meat	VCLOSE-neck meat	VCLOSE-neck meat
CLOSE-chuck roll	CLOSE-chuck roll	VCLOSE-chuck roll	VCLOSE-chuck roll
CLOSE-chuck roll cover	CLOSE-chuck roll cover	VCLOSE-chuck roll cover	VCLOSE-chuck roll cover
CLOSE-ribeye roll, cap on	CLOSE-ribeye roll, cap on	VCLOSE- ribeye roll, cap on	VCLOSE-ribeye roll
CLOSE-shoulder clod	CLOSE-shoulder clod	VCLOSE-shoulder clod	VCLOSE-rib blade meat
CLOSE-Infraspinatus	CLOSE-Infraspinatus	VCLOSE-Infraspinatus	VCLOSE-Triceps brachii
CLOSE-Supraspinatus	CLOSE-Supraspinatus	VCLOSE-Supraspinatus	VCLOSE-Infraspinatus
CLOSE-foreshank meat	CLOSE-foreshank meat	VCLOSE-foreshank meat	VCLOSE-Supraspintaus
CLOSE-brisket	CLOSE-brisket	VCLOSE-brisket	VCLOSE-foreshank meat
VCLOSE-Obliquus abdominis internus	VCLOSE-Obliquus abdominis internus	VCLOSE-Obliquus abdominis internus	VCLOSE-brisket
VCLOSE-flank steak	VCLOSE-flank steak	VCLOSE-flank steak	VCLOSE-Obliquus abdominis internus
VCLOSE-inside skirt	VCLOSE-inside skirt	VCLOSE-inside skirt	VCLOSE-flank steak
VCLOSE-Obliquus abdominis externus	VCLOSE-Obliquus abdominis externus	VCLOSE-Obliquus abdominis externus	VCLOSE-inside skirt
COMM-short rib (hindquarter; three ribs)	VCLOSE-short rib (hindquarter; three ribs)	VCLOSE-short rib (hindquarter; three ribs)	VCLOSE-Obliquus abdominis externus
COMM-tenderloin	VCLOSE-tenderloin	VCLOSE-tenderloin	VCLOSE-short rib (hindquarter; three ribs)
COMM-strip loin	CLOSE-strip loin	VCLOSE-strip loin	VCLOSE-tenderloin
COMM-top sirloin butt	CLOSE-top sirloin butt	VCLOSE-top sirloin butt, cap off	VCLOSE-strip loin
COMM-Tensor fasciae latae	VCLOSE-Tensor fasciae latae	VCLOSE-top sirloin cap	VCLOSE-Gluteus medius, Gluteus accessories removed
COMM-inside round, cap on	CLOSE-inside round, cap on	VCLOSE-Tensor fasciae latae	VCLOSE-top sirloin cap
COMM-bottom round	CLOSE-bottom round	VCLOSE-inside round, cap on	VCLOSE-Tensor fasciae latae
CLOSE-full knuckle	CLOSE-full knuckle	VCLOSE-outside round	VCLOSE-inside round, cap off

Table 3.1 Continued

Cutability endpoint			
COMM	CLOSE	VCLOSE	XCLOSE[b]
CLOSE-hindshank meat	CLOSE-hindshank meat	VCLOSE-Semitendinosus	VCLOSE-inside round cap
CLOSE-heel	CLOSE-heel	VCLOSE-full knuckle	VCLOSE-outside round
VCLOSE-Quadratus femoris	VCLOSE-Quadratus femoris	VCLOSE-hindshank meat	VCLOSE-Semitendinosus
		VCLOSE-heel	VCLOSE-full knuckle
		VCLOSE-Quadratus femoris	VCLOSE-hindshank meat
			VCLOSE-heel
			VCLOSE-Quadratus femoris

[a] Cutability endpoints: COMM = commodity trimmed cuts to a maximum fat thickness of one cm; CLOSE = closely trimmed cuts to a maximum fat thickness of 0.5 cm; VCLOSE = very closely trimmed cuts free of external fat (peeled or denuded); and XCLOSE = very closely trimmed cuts (peeled or denuded) that were further separated and trimmed.

[b] Saleable meat yield calculation of the XCLOSE cutability endpoint included the weight of lean trimmings generated during fabrication adjusted to zero percent fat by chemical lean measurements.

Table 3.2 Principal component scores calculated from output variables from a VIAscan beef carcass system that were allowed to enter regression equations and the percentage of standardized variance accounted for by each principal component score

Carcass characteristic	Principal component	Percentage of variance explained by principal component	Cumulative percentage of variance explained
Color	1st	48.2	48.2
	2nd	13.3	61.5
	3rd	5.6	67.1
	4th	5.1	72.2
	5th	3.8	76.0
	6th	3.3	79.3
	7th	3.0	82.3
	8th	2.6	84.8
	9th	2.3	87.1
	10th	2.0	89.1
Loin shape	1st	87.6	87.6
	2nd	7.4	95.0
	3rd	1.6	96.6
Round shape	1st	51.4	51.4
	2nd	15.7	67.1
	3rd	13.8	81.0
	4th	7.3	88.3
	5th	3.8	92.1

Table 3.3 Number of carcass sides tested, stratified by gender, carcass weight class, fat thickness class, and Uruguay National Institute of Meat muscle conformation score[a]

	Light steer[b]			Heavy steer[c]			Light female[d]				Heavy female[e]			
Fat class	N	A	C	N	A	C	N	A	C	U	N	A	C	Overall
< 0.6 cm	1	29	8	7	17	12	0	18	16	1	2	16	14	141
> 0.6 cm	0	22	0	10	25	4	3	36	2	0	14	25	6	147
Total	1	51	8	17	42	16	3	54	18	1	16	41	20	
Category Total		60			75			76				77		288

[a]Uruguay National Institute of Meat muscle conformation scores: heavy muscled = N; light muscled = A, C, and U.
[b]Light steer = hot carcass weight < 230 kg.
[c]Heavy steer = hot carcass weight ≥ 230 kg.
[d]Light female = hot carcass weight < 200 kg.
[e]Heavy female = hot carcass weight ≥ 200 kg.

Table 3.4 Descriptive statistics of carcass traits and fabrication yields for meat yield phase (n = 288)

Trait	Mean	SD	Minimum	Maximum	CV
Hot carcass weight, kg	224.6	41.2	149.0	374.2	18.3
Longissimus muscle area, cm^{2a}	49.7	8.4	30.5	85.3	16.9
Longissimus muscle area, cm^2 per kg of hot carcass weight	0.22	0.03	0.13	0.33	14.7
USDA preliminary yield grade	2.9	0.6	2.0	5.0	19.1
Adjusted fat thickness, cm	0.8	0.5	0.0	2.5	66.3
USDA yield grade[b]	2.8	0.6	1.3	4.7	22.8
COMM saleable meat yield, %[ci]	64.3	2.0	58.2	71.2	3.2
CLOSE saleable meat yield, %[di]	62.0	2.1	55.5	68.4	3.4
VCLOSE saleable meat yield, %[ei]	58.5	2.5	51.0	65.3	4.2
XCLOSE saleable meat yield, %[fi]	63.3	2.6	56.2	70.9	4.2
Fat, %[gi]	12.7	3.4	5.2	23.8	26.7
Bone, %[hi]	21.5	1.7	16.9	27.1	8.1
Lean to bone ratio[j]	3.0	0.2	2.3	3.8	7.8

[a] Measured at the 10th/11th rib interface using a Computer Vision System equipped with a BeefCam module.

[b] Calculated to the nearest 0.1 of a yield grade using a constant kidney, pelvic and heart fat of 0.5%.

[c] Includes all saleable cuts from a carcass side trimmed to a maximum fat depth of one cm.

[d] Includes all saleable cuts from a carcass side trimmed to a maximum fat depth of 0.5 cm.

[e] Includes all saleable cuts from a carcass side trimmed free of external fat (peeled or denuded).

[f] Includes all saleable cuts (some cuts are separated further than in VCLOSE saleable meat yield) trimmed free of fat. This yield also includes the weight of all trimmings generated during fabrication adjusted by chemical lean measurements to zero percent fat.

[g] Includes all waste fat from the production of VCLOSE saleable meat.

[h] Includes the weight of all bone and cartilage from a carcass side.

[i] All yields were calculated as a percentage of the gross side weight.

[j] XCLOSE saleable meat weight divided by the weight of all bone and cartilage from a carcass side.

Table 3.5 R^2 and root mean square error (RMSE) values for regression equations developed to predict actual saleable meat yields using Uruguayan National Institute of Meat (INAC) grades, USDA yield grade, output variables from a Computer Vision System equipped with a BeefCam module (CVS BeefCam), output variables from a VIAscan beef carcass system (BCS), and output variables from a CVS BeefCam and BCS[a]

	Saleable meat yield[b] R^2 (RMSE)			
Terms in model	COMM[c]	CLOSE[d]	VCLOSE[e]	XCLOSE[f]
INAC grades[g]	0.35 (0.017)	0.36 (0.017)	0.37 (0.020)	0.36 (0.020)
USDA yield grade[h]	0.37 (0.016)	0.41 (0.016)	0.52 (0.017)	0.53 (0.018)
CVS BeefCam output Percent fat	0.41 (0.016)	0.45 (0.015)	0.55 (0.016)	0.57 (0.017)
BCS output Dimensional ratio 1, 1st, 2nd, 3rd, and 10th carcass color principal components, and 1st principal component of round shape	0.49 (0.015)	0.52 (0.015)	0.58 (0.016)	0.59 (0.017)
CVS BeefCam and BCS output CVS BeefCam percent fat, BCS dimensional ratio 1, BCS 1st, 2nd, 3rd, and 10th carcass color principal components, and BCS 1st principal component of round shape	0.53 (0.014)	0.58 (0.014)	0.66 (0.014)	0.69 (0.015)

[a] Models were developed using stepwise selection procedures.

[b] Saleable meat yields were calculated as a percentage of the side gross weight.

[c] Commodity saleable meat yield includes all saleable cuts from a carcass side trimmed to a maximum fat depth of one cm.

[d] Closely trimmed saleable meat yield includes all saleable cuts from a carcass side trimmed to a maximum fat depth of 0.5 cm.

[e] Very closely trimmed saleable meat yield includes all saleable cuts from a carcass side trimmed free of external fat (peeled or denuded).

[f] XCLOSE saleable meat yield includes all saleable cuts (some cuts are separated further than in VCLOSE saleable meat yield) trimmed free of fat. This yield also includes the weight of all trimmings generated during fabrication adjusted by chemical lean measurements to zero percent fat.

[g] Predicted fabrication yields for INAC grades were obtained by using the mean fabrication yield for each of the 38 INAC grades represented in the meat yield phase.

[h] USDA yield grade was calculated to the nearest 0.1 of a yield grade using a constant kidney, pelvic and heart fat of 0.5% and the longissimus muscle area measured at the 10th/11th rib interface by a CVS BeefCam.

Table 3.6 R^2 and root mean square error (RMSE) values for regression equations developed to predict actual fat trim yields using Uruguayan National Institute of Meat (INAC) grades, USDA yield grade, output variables from a Computer Vision System equipped with a BeefCam module (CVS BeefCam), output variables from a VIAscan beef carcass system (BCS), and output variables from a CVS BeefCam and BCS[a]

Terms in model	Fat trim yield[b] R^2 (RMSE)
INAC grades[c]	0.54 (0.023)
USDA yield grade[d]	0.54 (0.023)
CVS BeefCam output Adjusted longissimus muscle area (cm^2 per kg of hot carcass weight), marbling area, and average fat thickness	0.65 (0.020)
BCS output Dimensional 20, dimensional ratio 1, dimensional ratio 18, area 12, total area, 1st, 2nd, 3rd, 5th, 6th, 8th, 9th and 10th carcass color principal components, 1st and 2nd round shape principal components, 3rd loin shape principal component and hot carcass weight	0.80 (0.016)
CVS BeefCam and BCS output CVS BeefCam percent fat, BCS dimensional 20, BCS area 12, BCS 1st, 2nd, 3rd, 4th, 6th, 9th and 10th carcass color principal components, BCS 2nd round shape principal component, and hot carcass weight	0.84 (0.014)

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[a] Models were developed using stepwise selection procedures.

[b] Fat trim yield = includes all waste fat from the production of VCLOSE saleable meat and was calculated as a percentage of the side gross weight.

[c] Predicted fabrication yields for INAC grades were obtained by using the mean fabrication yield for each of the 38 INAC grades represented in the meat yield phase.

[d] USDA yield grade was calculated to the nearest 0.1 of a yield grade using a constant kidney, pelvic and heart fat of 0.5% and the longissimus muscle area measured at the 10th/11th rib interface by a CVS BeefCam.

Table 3.7 R^2 and root mean square error (RMSE) values for regression equations developed to predict actual bone yields using Uruguayan National Institute of Meat (INAC) grades, USDA yield grade, output variables from a Computer Vision System equipped with a BeefCam module (CVS BeefCam), output variables from a VIAscan beef carcass system (BCS), and output variables from a CVS BeefCam and BCS[a]

Terms in model	Bone yield[b] R^2 (RMSE)
INAC grades[c]	0.54 (0.012)
USDA yield grade[d]	0.16 (0.016)
CVS BeefCam output Total area of the 10/11th rib interface, percent marbling, average fat thickness, and hot carcass weight	0.51 (0.012)
BCS output Dimensional ratio 36, 1st, 2nd, 3rd, 4th, 6th, 7th, and 9th carcass color principal components, 1st, 2nd, 3rd, and 4th round shape principal components, and hot carcass weight	0.61 (0.011)
CVS BeefCam and BCS output CVS BeefCam lean area of the 10th/11th rib interface, CVS BeefCam percent fat, BCS 1st, 2nd, 3rd, 4th, 6th, and 9th carcass color principal components, and BCS 1st, 2nd, and 3rd round shape principal components	0.63 (0.011)

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[a] Models were developed using stepwise selection procedures.

[b] Bone yield = includes the weight of all bone and cartilage from a carcass side and was calculated as a percentage of the side gross weight.

[c] Predicted fabrication yields for INAC grades were obtained by using the mean fabrication yield for each of the 38 INAC grades represented in the meat yield phase.

[d] USDA yield grade was calculated to the nearest 0.1 of a yield grade using a constant kidney, pelvic and heart fat of 0.5% and the longissimus muscle area measured at the 10th/11th rib interface by a CVS BeefCam.

Table 3.8 R^2 and root mean square error (RMSE) values for regression equations developed to predict the actual lean to bone ratio using Uruguayan National Institute of Meat (INAC) grades, USDA yield grade, output variables from a Computer Vision System equipped with a BeefCam module (CVS BeefCam), output variables from a VIAscan beef carcass system (BCS), and output variables from a CVS BeefCam and BCS[a]

Terms in model	Lean to bone ratio[b] R^2 (RMSE)
INAC grades[c]	0.33 (0.189)
USDA yield grade[d]	0.00 (0.232)
CVS BeefCam output Total area of the 10th/11th rib interface, average fat thickness, and hot carcass weight	0.33 (0.190)
BCS output Dimensional 13, area 1, dimensional ratio 5, 3rd, 9th, and 10th carcass color principal components, 1st, 2nd, 3rd, and 5th round shape principal components, and hot carcass weight	0.41 (0.181)
CVS BeefCam and BCS output CVS BeefCam total area of the 10th/11th rib interface, CVS BeefCam marbling area, CVS BeefCam maximum fat thickness, BCS dimensional 13, BCS dimensional ratio 5, BCS 3rd, 4th, and 10th carcass color principal components, and BCS 1st, 2nd, 3rd, and 4th round shape principal components	0.49 (0.169)

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[a] Models were developed using stepwise selection procedures.

[b] Lean to bone ratio = all lean generated from the carcass including fully divided saleable cuts trimmed free of fat and the weight of all trimmings generated during fabrication adjusted by chemical lean measurements to zero percent fat. This lean saleable meat weight was then divided by the weight of all bone and cartilage from a carcass side.

[c] Predicted fabrication yields for INAC grades were obtained by using the mean fabrication yield for each of the 38 INAC grades represented in the meat yield phase.

[d] USDA yield grade was calculated to the nearest 0.1 of a yield grade using a constant kidney, pelvic and heart fat of 0.5% and the longissimus muscle area measured at the 10th/11th rib interface by a CVS BeefCam.

Table 3.9 Descriptive statistics of USDA quality grade factors, Computer Vision System equipped with a BeefCam module (CVS BeefCam) output variables, and Warner-Bratzler shear force values for carcasses included in the tenderness phase (n = 345)

Trait	Mean	SD	Minimum	Maximum	CV
Hot carcass weight, kg	225.1	39.6	149.0	374.2	17.6
Longissmus muscle area, cm^{2}[a]	50.9	8.4	30.2	87.8	16.5
Skeletal maturity[b]	158.9	146.4	30.0	500.0	92.1
Lean maturity[bc]	138.9	96.0	20.0	430.0	69.2
Marbling score[d]	329.9	73.6	160.0	770.0	22.3
Lean L*[e]	33.8	3.0	25.7	43.1	8.7
Lean a*[f]	27.9	3.9	12.6	34.1	14.0
Lean b*[g]	12.9	1.5	7.9	17.2	11.6
Fat L*[e]	71.3	4.5	50.6	79.7	6.4
Fat a*[f]	7.7	2.1	1.9	22.1	27.1
Fat b*[g]	16.8	3.8	6.4	27.9	22.6
Warner-Bratzler shear force, kg	3.7	1.3	1.4	9.5	34.6

[a] Measured at the 10th/11th rib interface.

[b] Maturity: 0 = A^{00}; 100 = B^{00}; 200 = C^{00}; 300 = D^{00}; 400 = E^{00}.

[c] Lean maturity was not evaluated on dark-cutting carcasses (n = 60).

[d] Marbling score: 100 = Practically devoid^{00}; 200 = Traces^{00}; 300 = Slight^{00}; 400 = Small^{00}; 500 = Modest^{00}; 600 = Moderate^{00}; 700 = Slightly abundant^{00}.

[e] L* = the higher the value, the lighter the color.

[f] a* = the higher the value, the redder the color.

[g] b* = the higher the value, the more yellow the color.

Table 3.10 Correlation coefficients between Warner-Bratzler shear force (WBSF) values and output variables from a Computer Vision System equipped with a BeefCam module (CVS BeefCam)

CVS BeefCam output variable	WBSF			
	Data from images collected shortly after ribbing		Data from images collected approximately 50 min after ribbing	
	All carcasses	Dark-cutters excluded[a]	All carcasses	Dark-cutters excluded[a]
Adjusted longissimus muscle area (cm^2/kg of hot carcass weight)	0.06	0.03	0.08	0.06
Marbling	-0.13*	-0.08	-0.14*	-0.10
Lean L*	-0.12*	-0.27*	-0.12*	-0.28*
Lean a*	-0.10*	-0.35*	-0.11*	-0.40*
Lean b*	0.04	0.07	-0.11*	-0.24*
Fat L*	-0.17*	-0.21*	-0.15*	-0.20*
Fat a*	0.05	0.06	0.05	0.08
Fat b*	0.03	0.03	0.05	0.04

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[a] 60 carcasses were considered to be dark-cutters by visual appraisal, and were excluded.

*Correlation differs from zero ($P < 0.05$).

Table 3.11 Carcass characteristics and WBSF values when carcasses were classified into four groups using INAC grades[a]

	Group mean (SD)				
Trait	Young steer	Mature steer	Heifer	Mature cow	*P*
n	83	42	53	107	
LMA, cm^2	53.8^{x}	54.3^{x}	48.5^{y}	48.7^{y}	<0.001
	(9.1)	(8.7)	(6.1)	(7.9)	
Lean L*	34.9^{y}	33.4^{z}	36.6^{x}	34.0^{z}	<0.001
	(2.5)	(1.8)	(2.6)	(1.7)	
Lean a*	29.4^{y}	28.4^{yz}	30.5^{x}	28.5^{z}	<0.001
	(2.5)	(2.1)	(2.1)	(2.1)	
Lean b*	13.2	13.3	13.2	13.3	0.934
	(1.3)	(1.2)	(1.3)	(1.2)	
Fat L*	70.9^{y}	71.0^{y}	73.9^{x}	71.9^{y}	<0.001
	(4.5)	(3.8)	(2.9)	(4.6)	
Fat a*	7.7	7.5	7.2	7.9	0.195
	(2.3)	(1.8)	(1.7)	(1.9)	
Fat b*	15.0^{y}	16.5^{y}	16.3^{y}	19.4^{z}	<0.001
	(3.5)	(4.3)	(3.0)	(3.1)	
Marbling score[b]	314.7^{y}	357.1^{x}	324.5^{xy}	338.5^{xy}	0.015
	(55.1)	(81.1)	(80.4)	(80.9)	
Skeletal maturity[c]	64.5^{y}	89.8^{y}	76.8^{y}	326.6^{x}	<0.001
	(26.5)	(70.2)	(79.9)	(122.3)	
Lean maturity[c]	111.2^{y}	135.0^{y}	79.1^{z}	191.6^{x}	<0.001
	(73.1)	(85.8)	(64.4)	(102.6)	
WBSF, kg	3.6^{y}	3.3^{y}	3.4^{y}	4.2^{x}	<0.001
	(1.1)	(0.8)	(1.2)	(1.4)	

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[a] Carcasses considered to be dark-cutters ($\geq$ one-third USDA grade discount) by visual appraisal were excluded. Carcasses were classified according to gender and dentition. Young steers = steers with $\leq$ four permanent incisors; Mature steers = steers with $\geq$ six permanent incisors; Heifers = females with $\leq$ four permanent incisors; Mature cows = females with $\geq$ six permanent incisors.

[b] Marbling score: 100 = Practically devoid^{00}; 200 = Traces^{00}; 300 = Slight^{00}; 400 = Small^{00}; 500 = Modest^{00}; 600 = Moderate^{00}; 700 = Slightly abundant^{00}.

[c] Maturity: 0 = A^{00}; 100 = B^{00}; 200 = C^{00}; 300 = D^{00}; 400 = E^{00}.

[x, y, z] Means within a row that do not have a common superscript letter differ ($P < 0.05$).

Table 3.12 Carcass characteristics and WBSF values when carcasses were classified into three groups using USDA quality grades[a]

	Group mean (SE)			
Trait	1	2	3	*P*
n	97	90	98	
LMA, cm^2	51.3^{xy} (9.1)	53.0^{x} (8.0)	48.8^{y} (7.8)	0.003
Lean L*	35.6^{x} (2.3)	34.5^{y} (2.6)	33.8^{y} (1.9)	<0.001
Lean a*	30.3^{x} (1.8)	28.9^{y} (2.5)	28.3^{y} (2.2)	<0.001
Lean b*	13.5^{x} (1.2)	13.1^{y} (1.3)	13.2^{xy} (1.2)	0.045
Fat L*	73.3^{x} (3.4)	71.1^{y} (3.9)	71.1^{y} (5.2)	<0.001
Fat a*	7.6^{xy} (1.8)	7.3^{y} (2.2)	8.0^{x} (1.8)	0.033
Fat b*	17.2^{y} (3.2)	14.7^{z} (3.5)	19.3^{x} (3.4)	<0.001
Marbling score[b]	357.5^{x} (78.1)	295.4^{y} (42.3)	339.5^{x} (83.3)	<0.001
Skeletal maturity[c]	62.7^{y} (19.5)	75.0^{y} (45.1)	360.3^{x} (88.6)	<0.001
Lean maturity[c]	74.7^{z} (30.3)	129.3^{y} (75.3)	211.2^{x} (106.9)	<0.001
WBSF, kg	3.2^{z} (0.8)	3.7^{y} (1.3)	4.3^{x} (1.4)	<0.001

[a] Carcasses considered to be dark-cutters (≥ one-third USDA grade discount) by visual appraisal were excluded. USDA quality grades were used to segregate carcasses. Group 1 includes carcasses that received Prime, Choice, or Select grades; Group 2 includes carcasses that received the Standard grade; Group 3 includes carcasses that received Commercial, Utility, or Cutter grades.

[b] Marbling score: 100 = Practically devoid^{00}; 200 = Traces^{00}; 300 = Slight^{00}; 400 = Small^{00}; 500 = Modest^{00}; 600 = Moderate^{00}; 700 = Slightly abundant^{00}.

[c] Maturity: 0 = A^{00}; 100 = B^{00}; 200 = C^{00}; 300 = D^{00}; 400 = E^{00}.

[x, y, z] Means within a row that do not have a common superscript letter differ ($P < 0.05$).

Table 3.13 Mean Warner-Bratzler shear force values (SD) for longissimus steaks from Uruguayan beef carcasses segregated by use of output variables from a Computer Vision System equipped with a BeefCam module (CVS BeefCam)[a]

CVS BeefCam output variables	Steers and heifers[b]				Mature cows[c]			
	Low	Medium	High	*P*	Low	Medium	High	*P*
n	60	59	59		36	36	35	
Adjusted LMA[d]	3.4	3.4	3.5	0.988	4.3	4.0	4.4	0.566
	(1.1)	(1.0)	(1.2)		(1.5)	(1.2)	(1.4)	
Lean L*	3.8[x]	3.2[y]	3.4[xy]	0.005	4.9[x]	3.9[y]	3.9[y]	<0.001
	(1.3)	(0.7)	(1.0)		(1.6)	(1.2)	(1.1)	
Lean a*	3.8[x]	3.3[y]	3.2[y]	0.001	5.0[x]	3.9[y]	3.7[y]	<0.001
	(1.3)	(1.0)	(0.6)		(1.5)	(1.3)	(1.0)	
Lean b*	3.7[x]	3.4[xy]	3.2[y]	0.029	4.5[x]	4.4[xy]	3.8[y]	0.043
	(1.3)	(1.0)	(0.7)		(1.5)	(1.5)	(1.0)	
Fat L*	3.5	3.5	3.2	0.181	4.6[x]	4.4[xy]	3.7[y]	0.019
	(1.2)	(1.1)	(0.8)		(1.4)	(1.4)	(1.2)	
Fat a*	3.5	3.3	3.5	0.457	4.2	4.0	4.4	0.469
	(1.0)	(1.1)	(1.1)		(1.6)	(1.1)	(1.4)	
Fat b*	3.5	3.5	3.3	0.378	4.5	3.9	4.2	0.182
	(1.1)	(1.1)	(1.0)		(1.5)	(1.0)	(1.5)	
Marbling	3.5	3.6	3.2	0.124	4.2	4.2	4.2	0.984
	(1.1)	(1.2)	(0.8)		(1.2)	(1.4)	(1.6)	

[a] Carcasses considered to be dark-cutters (≥ one-third USDA grade discount) by visual appraisal were excluded. Low = the lowest one-third of carcasses for each CVS BeefCam output variable; Medium = the middle one-third of carcasses for each CVS BeefCam output variable; High = the highest one-third of carcasses for each CVS Beef output variable.

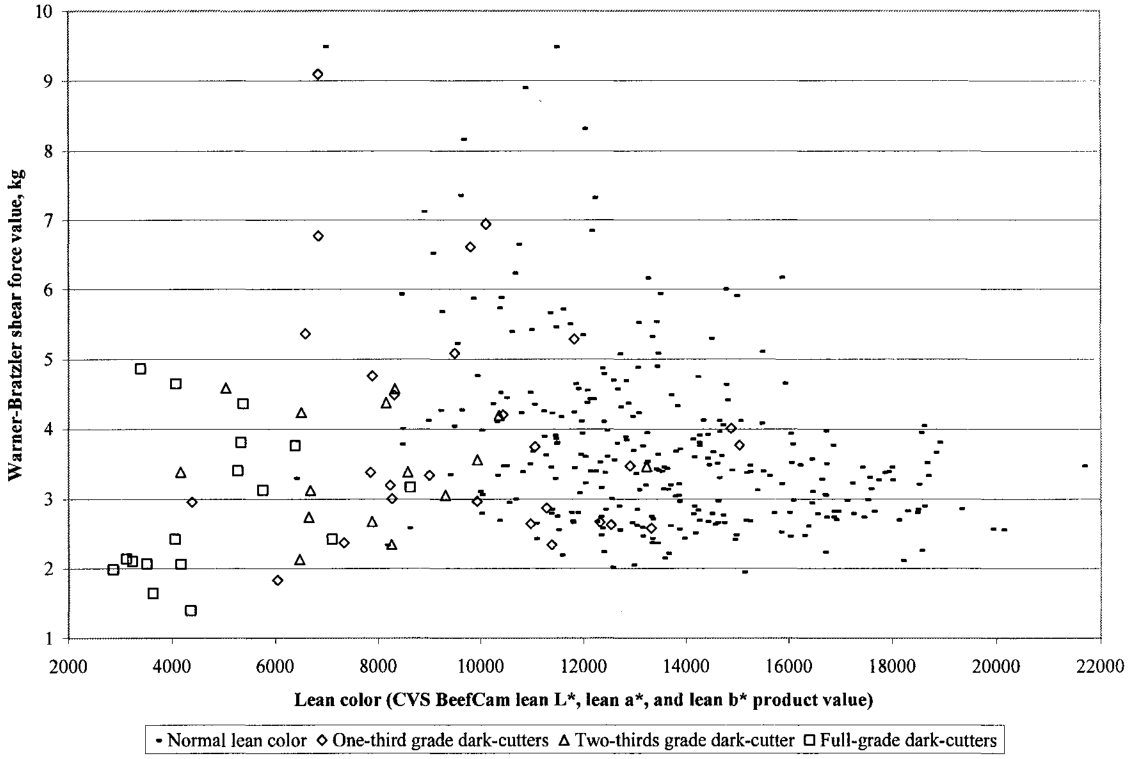
[b] Steer and heifer carcasses combined; heifer carcasses = females with ≤ four permanent incisors.

[c] Mature cows = female carcasses with ≥ six permanent incisors.

[d] Adjusted longissimus muscle area = cm^2 per kg of hot carcass weight.

[x, y] Means within a classification and row and that do not have a common superscript letter differ ($P < 0.05$).

Figure 3.1 Relationship between lean color [Computer Vision System equipped with a BeefCam module (CVS BeefCam) lean L*, lean a*, and lean b* product values] and Warner-Bratzler shear force values for one-third grade, two-thirds grade, and full-grade dark-cutters as well as for carcasses with normal lean color.



CHAPTER IV

USING REFLECTANCE SPECTROSCOPY TO PREDICT BEEF TENDERNESS

INTRODUCTION

Near-infrared (NIR) reflectance spectroscopy has been used to predict many characteristics of meat products including fat, water, and protein content (Togersen et al., 1999), energy content (Mitsumoto et al., 1991), water-holding capacity (Geesink et al., 2003), and tenderness (Hildrum et al., 1994; Byrne et al., 1998; Park et al., 1998). Near-infrared reflectance spectroscopy as a predictor of meat tenderness is advantageous because it can provide information related to tenderness in a non-destructive manner. Vote et al. (2003) reported that lean color measurements obtained from an online video image analysis system (Computer Vision System equipped with a BeefCam module; CVS BeefCam) were useful in segregating carcasses into groups that differed in the Warner-Bratzler shear force (WBSF) values of their longissimus steaks. The CVS BeefCam currently measures color in the visible portion of the spectrum by using the Commision Internationale de l'Eclairage (CIE) L*, a*, b* color space. This laboratory study was conducted to determine if reflectance measurements made in the NIR region of the spectrum were additive to reflectance measurements made in the visible region of the spectrum for predicting beef tenderness.

MATERIALS AND METHODS

Eighty-seven strip loins (Institutional Meat Purchase Specifications 180; USDA, 1988) were collected following fabrication over three days at a commercial beef processing facility from heifer carcasses with Slight or Traces marbling scores as determined by Colorado State University (CSU) personnel. Carcasses that received marbling scores of Traces or Slight were selected for use in this study in order to minimize the effect of marbling on reflectance values. Because of the relatively large scanning area of the HunterLab UltraScan (eight cm^2), reduced variability in marbling score would help ensure that differences in spectral curves were due to differences in lean color and not to the amount of marbling. Strip loins were placed in plastic bags, in boxes, and immediately transported to the Meat Science Laboratory at CSU. An approximate 10 cm section of the anterior end of each strip loin was cut to obtain a fresh cut surface for immediate spectroscopic measurement using a HunterLab UltraScan sphere spectrocolorimeter (Version 1.6, HunterLab, Reston, VA). Care was taken to avoid large flecks of marbling and three spectroscopic measurements were made on different locations per strip loin section. Percent reflectance values from 375 to 1100 nm in five nm intervals were recorded for each scan and averaged per strip loin before data analysis. Spectroscopic measurements were made at approximately 50 h postmortem. Each strip loin was then vacuum-packaged and aged at 2°C until 14 d postmortem.

At the end of the aging period, strip loins were frozen and stored at -20°C for subsequent evaluation of Warner-Bratzler shear force (WBSF) determination. Frozen strip loins were fabricated, in the frozen state, to yield a 2.54 cm thick steak using a band saw. Steaks were thawed for 24 h at 4°C (precooking internal steak temperatures were monitored to ensure that the steaks were between 1 and 5°C) before cooking for WBSF determination. Steaks were then cooked using a Magikitch'n belt grill (Magigrill model TBG-60; Magikitch'n Inc., Quakertown, PA) set to cook steaks to an endpoint temperature of 70°C (settings: top heat = 177°C, bottom heat = 177°C, preheat = disconnected, height = 1.85 cm, cook time = 6 min 35 s). Final endpoint temperatures were monitored using a hand-held thermometer (model HH21 thermometer; Omega Engineering, Inc., Stamford, CT). Cooked steaks were allowed to cool to room temperature (25°C) before removing 6 to 8 cores (1.27 cm in diameter) parallel to the muscle fiber orientation (AMSA, 1995). A single, peak shear force measurement was obtained for each core using a WBSF machine (G-R Electric Manufacturing Co., Manhattan, KS). Individual-core peak shear force values were averaged to assign a mean peak WBSF value to each steak.

Statistical Analysis.

All statistical analyses were performed using SAS (SAS Inst. Inc., Cary, NC). Simple correlation coefficients were computed between reflectance values and WBSF values. Strip loins were classified into two groups to determine if mean reflectance values differed between strip loins that yielded tender (WBSF < 4.5kg) and tough (WBSF ≥ 4.5kg) steaks. Mean reflectance values were then tested using ANOVA and means were separated using the Tukey-Kramer method when *F*-tests were significant at $\alpha = 0.05$.

In order to determine if reflectance measurements obtained in the infrared spectral region were additive to reflectance measurements obtained in the visible spectral region for predicting WBSF values, the following analyses were employed. To reduce the number of independent variables available to be included in regression models, and to simulate measurements that would be obtained using a system that made broad-band measurements of the spectral curve, reflectance values were averaged for regions of the spectral curve. The reflectance values at five nm intervals were averaged for the following regions: A = 375 to 410 nm, B = 415 to 430 nm, C = 435 to 445 nm, D = 450 to 545 nm, E = 550 to 700 nm, F = 705 to 805 nm, G = 810 to 955 nm, and H = 960 to 1100 nm. First, separate linear regression models were developed using forward model selection procedures with the α level set at 0.15 for an independent variable to enter the model for regions A through E, F through H, and all regions. Secondly, separate linear regression models were developed using forward model selection procedures with the α level set at 0.15 for an independent variable to enter the model from regions A through E, F through H, and all regions, this time allowing squared terms of regions and interactions between regions to enter the model. A third set of linear regression models were developed from principal component scores calculated using the five nm interval reflectance values over the visible spectrum (375 to 700 nm), NIR spectrum (705 to 1100 nm), and the entire measured spectrum (375 to 1100 nm) again using forward model selection procedures with the α level set at 0.15 for an independent variable to enter the model. The principal component scores allowed to enter regression equations along with the proportion of standardized variance accounted for by each principal component score are provided in Table 4.1.

RESULTS

Descriptive statistics for quality traits of carcasses from which strip loins were obtained for HunterLab UltraScan measurements and for WBSF values for steaks from those carcasses are presented in Table 4.2. Figure 4.1 displays the spectral curves for the strip loins used in this study, as well as the simple correlations between reflectance values and WBSF values. Correlation coefficients increased rapidly from approximately 405 nm to a peak at 415 nm ($r = -0.27$) and then declined rapidly to $r = -0.11$ at 450 nm. Correlation coefficients remained low from 450 nm through 700 nm but increased steadily from a minimum at 605 nm ($r = -0.08$) to another peak at 1065 nm ($r = -0.34$). Figure 4.2 displays the average reflectance values for tender (WBSF < 4.5 kg; $n = 45$) and tough strip loins (WBSF ≥ 4.5 kg; $n = 42$) as well as the difference between the average tender spectral curve and the average tough spectral curve. The differences between the average tender vs. tough spectral curves were clearly noticeable starting at 650 nm through 1100 nm with a maximum difference observed at 1070 nm (Figure 4.2).

Results of using different methods of regression analyses to predict WBSF values are presented in Table 4.3. Regression equations without squared terms or interactions between spectral regions were similar in their R^2 and root mean square error (RMSE) values. Regression equations developed using only regions in the visible range of the spectrum accounted for more variation than did regression equations developed from only the NIR regions of the spectrum. Additionally, there was no improvement, in R^2 or RMSE values for regression equations developed from the entire spectrum, over regression equations developed from only the visible regions. Use of principal component scores in regression equations actually resulted in lower R^2 and higher RMSE values than regression equations developed from reflectance values averaged over regions of the spectrum.

DISCUSSION

There are at least two different methods by which NIR spectroscopy could be applied to predict beef tenderness. One method would be through the use of a fiber optic probe that is inserted directly into a muscle to obtain NIR measurements. The use of fiber optic probes have been reported to be able to measure differences in connective tissue amount by obtaining measurements in the ultraviolet region of the spectrum (Swatland, 1995). The use of fiber optic probes to measure the NIR portion of the spectrum also has been studied to predict properties of beef related to tenderness. Another method of applying the use of NIR measurements would be by measuring the reflectance at the surface of a beef cut. In adding a NIR component to a video image analysis system, the most likely application would be to add broad-band wavelength filters to capture reflectance measurements over regions of the NIR portion of the spectrum. Because this study was conducted with that objective in mind, the methods used in this study differ somewhat from the methods used in other studies that report on the use of NIR measurements to predict beef tenderness.

Mitsumoto et al. (1991) reported that NIR measurements were highly correlated with shear force values, and moisture, protein, fat, and energy contents of several different beef cuts. However, because several different muscles were used in the Mitsumoto et al. (1991) study, it was unclear whether or not NIR measurements would be as highly correlated if just a single muscle (e.g., the longissmus muscle) were used. The range of WBSF values used in this study was much less than the range of WBSF values reported by Byrne et al. (1998) and Park et al. (1998). Hildrum et al. (1994; 1995) collected NIR measurements on longissimus samples from bulls and cows but not on longissimus samples from young, grain-fed cattle. Park et al. (1998) collected NIR measurements on steaks that had been aged for seven or 14 d postmortem, frozen and then thawed rather than collecting measurements from fresh beef aged for a short period of time. Hildrum et al. (1995) made NIR measurements on both fresh and thawed beef longissimus samples and reported that better predictions of WBSF values were obtained from the frozen and then thawed samples. The latter researchers explained that the NIR measurements could be detecting differences between tender and tough beef samples that may originate during thawing; they concluded that it could have been those differences that attenuated the prediction of tenderness. The regions of the NIR spectrum have differed between studies as Hildrum et al. (1994), Hildrum et al. (1995), and Park et al. (1998) recorded measurements from 1100 to approximately 2500 nm.

Differences also exist between studies in the chemometric analyses of NIR measurement data. Park et al. (1998) used a mean smoothing technique as described by Hruschka (1987) and computed the second derivative of NIR spectra before allowing mean values, differences between values, and ratios of values to be included in multiple linear regression equations. These methods were not employed for the present study because they require that the "full spectra" or wavelengths be measured at close intervals to reproduce a spectral curve (Hruschka, 2001) and if broad-band wavelength filters are used on an instrument then it may not be possible to calculate these variables. Partial least squares regression has been widely used in the analysis of spectral data. The latter method differs from principal component analysis in that, in addition to trying to account for as much variation as is possible between independent variables, partial least squares regression tries to simultaneously account for as much variation as possible in the dependent variable or variables. In the case of predicting WBSF values, because there is only one dependent variable, partial least squares regression analysis attempts to find successive combinations of independent variables that are orthogonal to each other to maximize the amount of variation in WBSF values explained for each combination of the independent variables. Park et al. (1998) reported that by using partial least squares regression, 63% of the variation in WBSF values was accounted for on a validation subset of the data. Byrne et al. (1998) however, employed principal component regression and partial least squares regression and reported that the models developed using principal component regression were more accurate for predicting beef tenderness than models developed from partial least squares regression.

The study conducted by Byrne et al. (1998) most closely matches the methods used in the present study. In that study, when NIR measurements were used in principal components regression, a multiple correlation coefficient of 0.69 was obtained for the prediction of WBSF values (Byrne et al., 1998). Use of principal components regression in the present study accounted for less variation in WBSF values than did the use of multiple linear regression, suggesting that, in the process of developing principal components to account for variation among independent variables, information that was useful for explaining differences in WBSF values was lost. The results of the regression analyses indicate that although the correlation coefficients between reflectance values and WBSF values are relatively high for the NIR region, the information provided by obtaining reflectance values in the NIR region is already provided by reflectance measurements made in the visible portion of the spectrum.

IMPLICATIONS

Reflectance measurements obtained in the near-infrared region of the light spectrum were correlated with Warner-Bratzler shear force values, however, these measurements were not additive to the predictive ability of reflectance measurements made in the visible portion of the spectrum when the use of broad-band wavelength filters on video image analysis equipment were simulated.

Table 4.1 Principal component scores allowed to enter regression equations and the percentage of standardized variance accounted for by each principal component score

Portion of the spectrum	Principal component	Percentage of variance explained by principal component	Cumulative percentage of variance explained
Visible only[a]	1st	91.3	91.3
	2nd	6.4	97.7
	3rd	1.4	99.1
Infrared only[b]	1st	95.2	95.2
	2nd	4.6	99.8
	3rd	0.1	99.9
Whole spectrum	1st	86.8	86.8
	2nd	8.9	95.6
	3rd	3.3	98.9

[a] Only regions A through E were used to calculate principal component scores.

[b] Only regions F through H were used to calculate principal component scores.

Table 4.2 Simple statistics for quality traits of carcasses from which strip loins (n = 87) were obtained for HunterLab Ultrascan measurements and for Warner-Bratzler shear force values for steaks from those carcasses

Trait	Mean	SD	Minimum	Maximum	CV
Skeletal maturity	74	28	40	190	37.7
Lean maturity	63	14	43	117	22.9
Marbling score	350	33	240	397	9.5
14d WBSF, kg	4.6	0.8	3.0	7.7	18.1

Table 4.3 Results of using different methods to predict the average Warner-Bratzler shear force values of strip loin steaks[a]

	Visible only[b]			Infrared only[c]			Whole spectrum		
Prediction method	Terms in model	R^2	RMSE	Terms in model	R^2	RMSE	Terms in model	R^2	RMSE
Linear regression	A, B, C, D, E	0.22	0.760	F, H	0.14	0.784	A, C, F, H	0.19	0.767
Linear regression including interactions and squared terms	B, C, AxE, CxD, B^2	0.23	0.754	H, FxH	0.14	0.781	AxE, CxE, BxH	0.20	0.761
Principal component regression[d]	PC2, PC3	0.07	0.814	PC1, PC2	0.13	0.788	PC1, PC2, PC3	0.15	0.781

[a] To reduce the number of independent variables available to be included in regression models and to simulate measurements that would be obtained using a system that made broad band measurements of the spectral curve, reflectance values at five nm intervals were averaged for the following regions: A = 375 to 410 nm, B = 415 to 430 nm, C = 435 to 445 nm, D = 450 to 545 nm, E = 550 to 700 nm, F = 705 to 805 nm, G = 810 to 955 nm, and H = 960 to 1100 nm.

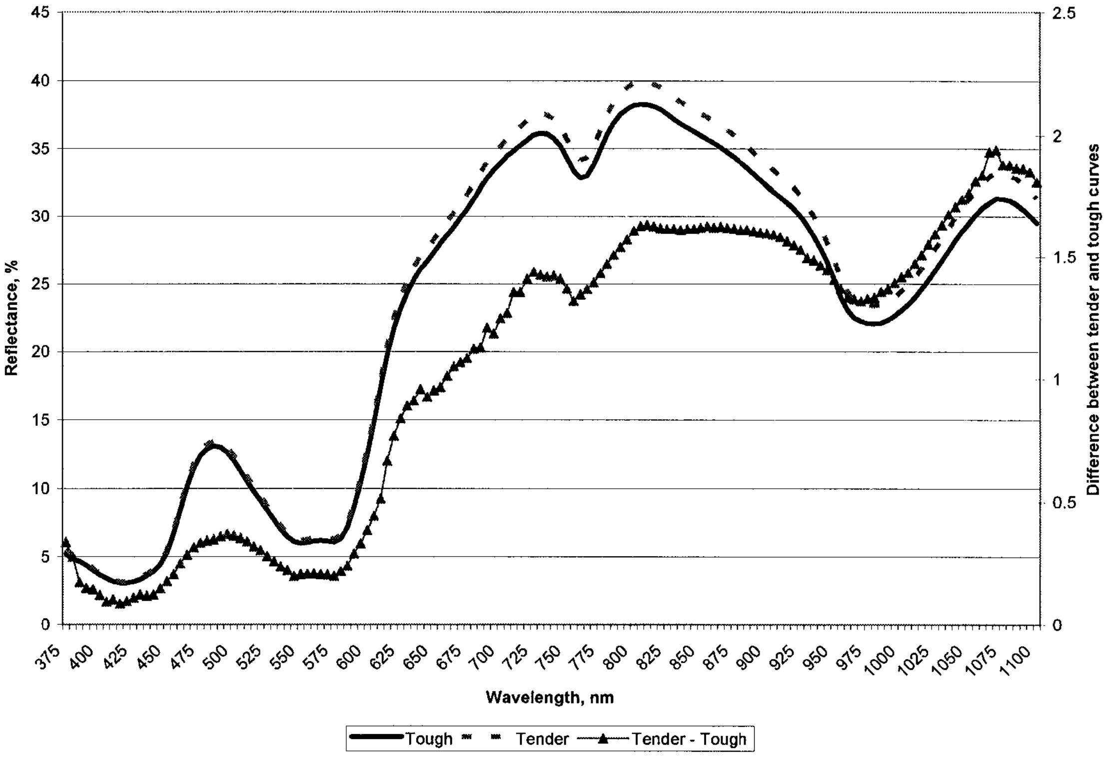
[b] Only regions A through E were allowed to enter regression models or principal component scores.

[c] Only regions F through H were allowed to enter regression models or principal component scores.

[d] PC1 = first principal component; PC2 = second principal component; PC3 = third principal component.

Figure 4.1 Spectral plot of strip loin samples scanned using a HunterLab Ultrascan and the simple correlation values between percent reflectance values and the Warner-Bratzler shear force values of steaks. Simple correlation values < −0.21 differ from zero (P < 0.05).

Figure 4.2 Mean spectral values for tender [Warner-Bratzler shear force (WBSF) value < 4.5 kg] strip loins and tough (WBSF value ≥ 4.5 kg) strip loins. Mean spectral values for tender and tough strip loins differed ($P < 0.05$) at 420 nm, 425 nm, and from 955 to 1100 nm.



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