An On-Line System to Assess Beef Quality Characteristics

PROJECT CODE:	**2017-1070**
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DATE SUBMITTED:	**Feb 2019**
DATE PUBLISHED:	April 2019
PUBLISHED BY:	Australian Meat Processor Corporation

The Australian Meat Processor Corporation acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

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1.0 EXECUTIVE SUMMARY

The goal of this project was to evaluate the TenderSpec^{TM} beef classification system for tenderness and marbling using Australian cattle. The specific objectives were:

1. Evaluate the TenderSpec^{TM} beef classification system against Australian beef for the capability to forecast beef tenderness class from an image taken earlier postmortem.

2. Document the capability of the TenderSpec^{TM} beef classification system to evaluate marbling within the ribeye.

3. Collect data so that future algorithms could be optimized for tenderness and marbling classification of Australian beef.

The system was shipped to Australia and more than 1,100 images were collected on beef sides in motion at a beef packing plant. Nearly 400 meat samples were collected and evaluated for shear force and intramuscular fat content. This research was a test of existing algorithms, not to optimize existing algorithms for the Australian market. Rather, this could be considered a proof of concept for use of the TenderSpec^{TM} beef classification system in the Australian market.

The primary reason to do the work is because tenderness is one of the most important palatability traits driving consumer satisfaction. No other equipment is commercial-ready, able to be installed on-line to operate at commercial speeds to identify beef carcasses that can be certified as tender. Such capacity would benefit producers of quality meat, improve the domestic market, and help Australia to hold or expand new international markets. Research has shown that consumers are willing to pay extra for beef that can be guaranteed tender.

The TenderSpec^{TM} beef classification system was installed in a commercial beef packing plant in Queensland. During a two week interval in February and March of 2018, images were taken on beef carcasses the day after harvest. A portion of the samples came from carcasses that had been suspended from the pelvis (Tenderstretch) and a portion from carcasses suspended by the Achilles tendon. The percentage *Bos indicus* was estimated and gender was recorded. Samples from the ribeye (Longissimus muscle) were removed, vacuum packaged and shipped to a reference laboratory for aging (14 d postmortem, never frozen), cooking and shear testing for tenderness. Additional samples were used to determine IMF. Goldfinch Solutions, LLC used their proprietary software to evaluate the images and classify samples at Tender or Uncertified. Marbling score was also determined from this camera-based, multispectral system.

The TenderSpec^{TM} beef classification system met the statistical criterion of 95% accuracy in identifying carcasses that could be certified as tender. That is, when a carcass is certified as tender, the certification was 95% accurate. About 85% of the beef tested could carry this certified Tender designation. Marbling scores derived from the U.S. algorithm were more highly related to IMF than were MSA marbling scores.

The project also reinforced some well-known relationships, including that Tenderstretch improves loin muscle tenderness, higher percentages of *Bos indicus* breeding can be detrimental to tenderness, and that heifers are slightly less tender than steers.

These results indicate that the TenderSpec^{TM} beef classification system is capable of identifying tender beef carcasses. Application of this technology in Australian beef plants has the capacity to benefit producers, the domestic market, and global competitiveness.

In addition, a database now exists to facilitate development and optimization of algorithms for tenderness, marbling, and other traits collected with the MSA system. It is recommended to fund development of the algorithms straightaway. In the meantime, the system can perform well in the Australian market.

2.0 INTRODUCTION

A recent U.S. study showed that 81% of overall beef palatability score can be explained by tenderness (Emerson et al., 2013). Although flavor is also an important sensory trait, tenderness plays a predominant role in customer satisfaction (Huffman et al., 1996). In a recent annual survey conducted by the National Cattlemen's Beef Association (2017) a third of respondents disagreed or strongly disagreed with the statement that "beef is always tender." In contrast, over 90% agreed with the statement that "beef tastes great". Thus, attention to beef tenderness is an important role for the meat industry.

In 2015, Tatum (2015) estimated the odds of obtaining a slightly tough or tougher rating for supermarket beef of 15-25% for low Choice and Select-grade strip steaks. Using a trained sensory panel, Emerson et al. (2013) showed that low Choice strip steaks had a 38% likelihood of yielding an unsatisfactory sensory rating, while Select-grade steaks were 71% likely to give an unsatisfactory eating experience. Most beef in Australia would fall into the low Choice and Select-grade categories. It's clear that Australia could benefit from technology capable of identifying tender beef. This is true in the domestic as well as the global marketplace.

Research by Feuz et al. (2004), Boleman et al. (1997), Lusk et al. (1999), Shackelford et al. (2001) and Miller et al. (2001) indicates that consumers are willing to pay a premium for beef that can be guaranteed tender, and that the premium could range from $2.71 to $5.29 USD/kg at retail. So, there is value in being able to certify beef as tender. The U.S. Department of Agriculture has a policy to recognize the muscles in a beef carcass as tender that are equal or superior to the ribeye in tenderness, when the ribeye itself can be certified as tender. This means a 900 pound (409 kg) carcass would yield 155 pounds (70 kg) of cuts that could be certified as tender. Using $4.00 USD per kg as a premium (the average of projected premiums from the research cited at the beginning of this paragraph), a single carcass certified as tender could generate an additional $280 USD at retail.

To date, there is no commercially available, accurate, non-destructive device capable of predicting tenderness class in a beef packing plant at line speeds. Should it become possible to do so, the industry could better send signals to producers and better meet consumer desires – a situation that would return more dollars to producers and packers.

Tenderness is a complex biological property and it cannot be observed by the human eye. That's because tenderness is related to both muscle structure and biochemical activity (Webb et al., 1964). Some aspects of muscle structure can be observed at high magnification. Some aspects of biochemical activity can only be perceived in the non-visible region of the light spectrum. In particular, the near infrared spectrum has proven rich in information related to meat tenderness. We (Goldfinch Solutions, LLC) have developed technology that uses both aspects of meat tenderness to identify beef carcasses that can be certified as tender. The TenderSpec™ beef classification system can certify tender beef with 95% accuracy.

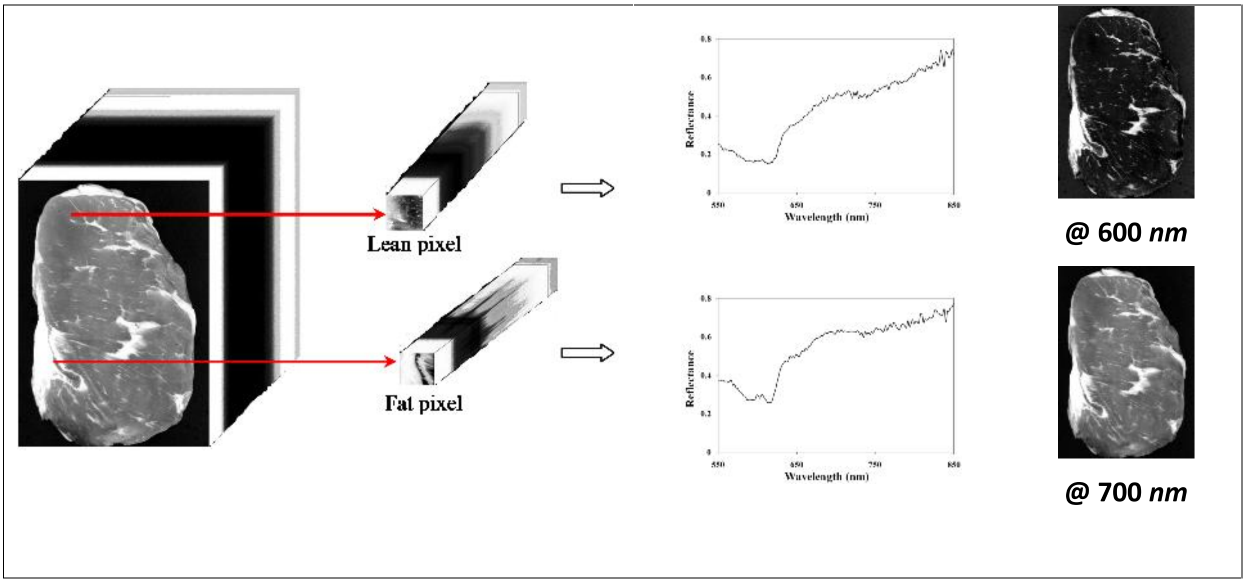


Figure 3. A hyperspectral image of a beef steak showing typical spectral signatures of lean and fat pixels and gray scale or tonal images of a beef steak at selected wavelengths or bands.

The foundation of our technology is hyperspectral imaging, which provides a spectral reflectance curve on every pixel in an image (Figure 3). Given the camera resolution and the visible and NIR regions of the light spectrum that are surveyed, a considerable amount of information can be obtained. From a composite image we extract features that are related to many of the biochemical and structural features that impact meat tenderness, including muscle pH, sarcomere length (degree of contraction), extent of proteolysis, collagen characteristics, composition, and color (Felter, 2007). As a result, the system operates on the basis of biology, not just random statistical relationships to the trait of interest. This leads to a more robust and accurate system.

The MSA grading system attempts to classify carcasses and cuts on the basis of tenderness. The features used to determine the MSA grade are all related to tenderness through the structural and biochemical elements used by the TenderSpec™ beef classification system. As a result, the TenderSpec™ beef classification system should be equal or superior at identifying tender meat to the MSA grading system. An added advantage is that it can do so on-line in a meat plant, while the carcasses are in motion. Results are available in near real time (within seconds), allowing for carcasses to be sorted into marketing groups based on tenderness and other carcass characteristics.

The TenderSpec™ beef classification system obtains an image of the ribeye at the junction between the rib and the loin. The image is typically obtained between 1 and 2 days postmortem. This provides the opportunity for the system to estimate intramuscular fat content (or, in the U.S., marbling score) and loin muscle area. Tenderness class is forecast for 14 d postmortem, the typical time between harvest and retail sale.

The TenderSpec™ beef classification system has been developed and optimized on U.S. beef. While there are some notable differences between Australian cattle and U.S. cattle, there is every reason to believe that the system can perform equally well in Australia as it does in the U.S. Therefore, this project was conceived to evaluate existing algorithms for tenderness and marbling (intramuscular fat) in Australian cattle.

3.0 PROJECT OBJECTIVES

The objectives of this project were to:

1. Evaluate the TenderSpec™ beef classification system against Australian beef for the capability to forecast beef tenderness class from an image taken earlier postmortem.

2. Document the capability of the TenderSpec™ beef classification system to evaluate marbling within the ribeye.

3. Collect data so that future algorithms could be optimized for tenderness and marbling classification of Australian beef.

The project had 8 milestones. They were:

1. Signing of the agreement.

2. A project logistics trip to visit potential collaborating meat plants and the reference lab at the University of New England.

3. Shipping the TenderSpec™ beef classification system to Australia.

4. Collecting images and meat samples from 400 carcasses.

5. Collecting reference data for tenderness (shear force) and intramuscular fat. This milestone was conducted by the University of New England.

6. Construction of a database to facilitate statistical analysis.

7. Statistical analysis of the data, including an evaluation of distribution and variability of tenderness and marbling in the sample of Australian beef.

8. Submission of a SnapShot and Final Report.

4.0 METHODOLOGY

Project Description:

4.1 General approach

The overall goal of this project was to evaluate the TenderSpec™ Beef Classification system for objective assessment of ribeye quality traits - tenderness and marbling - in Australian beef. There were two primary objectives to this project. One was to evaluate the capability of the TenderSpec™ Beef Classification system to identify tender cattle in Australia. The other was to compare marbling scores established by the TenderSpec™ Beef Classification system to measures of intramuscular fat in Australian cattle.

To accomplish the overall goal, we made two trips to Australia. From January 5 – 13, 2018 a site visit to identify potential meat plant collaborators was made. In addition, a visit to the research labs at

University of New England with Dr. Peter McGilcrist was made to review laboratory procedures for the project. Australian Country Choice was selected as the cooperating plant.

From Feb. 21 – March 10, a team from Goldfinch Solutions and University of New England traveled to Brisbane to collect sample images and meat samples. A sample of the longissimus muscle was obtained spanning the 12th – 13th ribs. Meat was vacuum packaged, transported to the University of New England, and subsequently measured for shear force tenderness (14 d postmortem, never frozen) and intramuscular fat (IMF) content. Adjusting for incomplete data, we ended up with images from 1112 sides and meat tenderness/IMF data on 376 carcasses.

4.2 TenderSpec Beef Classification System

The overall goal of this project is to evaluate the TenderSpec™ Beef Classification System for objective assessment of ribeye quality traits, including tenderness (day 14) and marbling, in Australian beef. An objective evaluation of carcass quality characteristics is needed to deliver high quality products, differentiate Australian beef in the global market, and increase processing efficiency.

The TenderSpec™ Beef Classification System is a multispectral imaging system capable of acquiring key visible and near-infrared wavelength images that are central to predicting beef tenderness and other quality traits. The speed (< 4 seconds) and accuracy (95% for beef tenderness classification) of this system make it suitable for real-time applications in commercial beef packing plants. Images of beef ribeye muscle were acquired and analyzed to predict tenderness (day 14) and marbling. The accuracy of the system in predicting the ribeye quality traits in Australian beef was evaluated.

Successful completion of the proposed work provided an accurate and objective evaluation of the TenderSpec™ Beef Classification System in predicting the quality traits of Australian beef. The technology can improve economic opportunities, provide a mechanism to identify high quality beef, and gain domestic and international market share for Australian beef by differentiating it by quality.

This study was conducted to evaluate the TenderSpecTM Beef Classification System. The system is comprised of a custom-built camera assembly, an electronics console, and a cable to connect the two (Figures 1, 2). The camera assembly has a multispectral camera, lens, high-power LED lights, and an image-capture trigger. The system is operated by a laptop, although a commercially-friendly console is also available (Figure2). The camera is connected to the laptop through a gigabit Ethernet port. The hood for the camera is coated with a light-diffusing substance for uniform illumination. The camera hood has a locating bar and pins to ensure proper placement on the ribeye surface. It takes less than a second to capture an image for analysis and the software is capable of determining the tenderness classification and carcass grading characteristics in just a few seconds. Thus, the entire device can operate at line speeds in a commercial meat plant.

[a]. Multispectral imaging system. [b]. Camera assembly. [c]. Image acquisition on moving carcasses in a beef packing plant.

Figure 1. The TenderSpec™ Beef Classification System.

Figure 2. The TenderSpec™ Beef Classification System ready for operation.

4.3 Carcass Selection

Each day, pens of cattle at the lairage were identified when visual assessment or prior knowledge about the cattle suggested there was a high percentage of *Bos taurus* (0-25% *Bos indicus*), the cattle had been fed grain in a feedlot, and where they were judged to be young. At harvest, an experienced assessor estimated the percentage *Bos indicus* and qualifying carcasses were identified. The intent was for about half or more of the samples to come from cattle identified as having 0-25% *Bos indicus* and the other half from cattle having 50% or more of *Bos indicus* breeding.

Where possible, one side of a carcass was suspended from the Achilles tendon and the other side was suspended using the Tenderstretch method (Figure 4). There were problems with the hoist in the facility, which means that on occasion just Tenderstretch-hung sides were available.

Figure 4. Alternating carcass suspension methods.

Figure 5. Sample removal location.

The next morning, marked carcasses were ribbed at the 13th rib and allowed a minimum of 0.5 hours to bloom. Sides were then presented to the TenderSpec^{TM} Beef Classification System on a moving rail. One image was acquired on each side. Images were captured at line speeds – the chain was not stopped for image capture. Subsequently, MSA grading data were obtained.

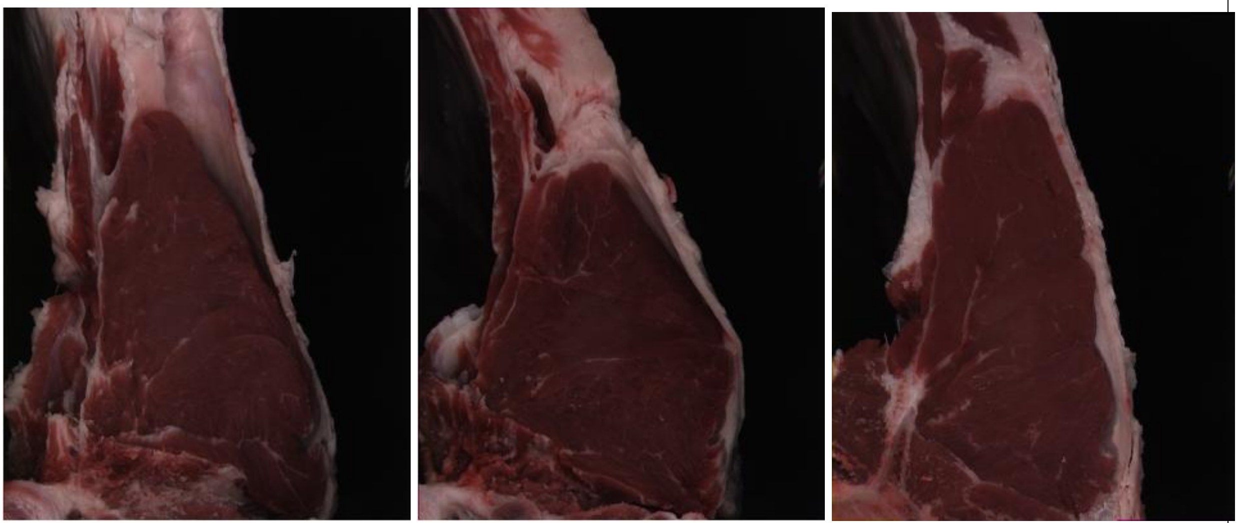
Each day prior to image capture, the grading camera was calibrated using a white reference plate and a sample beef ribeye image.

A sample of the longissimus muscle was obtained spanning the 12th – 13th ribs (Figure 5). Meat was vacuum packaged, transported to the University of New England, and subsequently measured for shear force tenderness and intramuscular fat content.

4.4 Image Acquisition

The TenderSpec™ Beef Classification System was used to acquire images of beef ribeye muscle on chilled, hanging carcass of grain-fed beef. More than 1,100 images representing different production days were acquired. The system consisted of an electronic console and a camera module. The camera was suspended from a load balancer such that images of moving carcasses could be made. The camera was placed on a ribbed carcass and images of the cut ribeye muscle surface were acquired.

Some image artifacts can occur during image capture. Figure 6 shows some examples. An additional problem can be seen in part (c) where the camera is tilted and not in the same plane as the ribeye. We have developed methods and algorithms to address these issues.



[a]. Retracted muscle. [b]. Misshaped ribeye. [c]. Portion of tenderloin.

Figure 6. Examples of beef carcass artifacts caused by plant operations that can affect the accurate prediction of ribeye area and fat thickness.

4.5 Reference Data

During image acquisition, MSA data were collected for pH, loin muscle area, fat thickness, pH, color and marbling. We did not collect samples from carcasses with pH values or color scores that were too high. We also avoided damaged carcasses and tried to ensure that Tenderstretch samples always had a companion side that was hung by the Achilles tendon.

Marbling score and fat content were collected and used as reference data. Large, 10 cm -thick ribeye samples were excised from each ribeye sample, vacuum packaged, and sent to the University of New England (Dr. Peter McGilcrist) for shear force measurements after 14 days of ageing (never frozen). Two steaks per carcass (2.5 cm thick) were used to measure tenderness to ensure accurate shear force measurement. The third steak was used for objective measurement of intramuscular fat content.

Shear force was measured by the University of New England using their standard protocol (Perry et al., 2001). Steaks were placed in individual plastic bags and held at 4 C to standardize temperature. They were immersed in a 70 C circulating water bath for 60 minutes. Immediately after cooking, bags were placed in a cool, circulating water bath to remove heat and stop any additional cooking. Subsequently, chilled samples were cut into segments such that were 15 x 67 mm in cross section. The segments were removed in such a way that muscle fiber direction was parallel to the long axis and shear force was made perpendicular to fiber direction. Shear force was obtained on 6 segments per steak.

Intramuscular fat content was determined on raw, homogenized steak samples that were freeze dried (Perry et al., 2001). Freeze-dried samples were analyzed in a Technicon Infralyser.

4.5. Image Analysis, Prediction Models, and Evaluation

The images were first calibrated to reduce variations due to lighting and camera response. Then, the ribeye measurement region was isolated and important image features were extracted using proprietary software.

Existing, proprietary algorithms were used to predict tenderness class (day 14) and marbling.

Certification accuracy was used as the evaluation metric for tenderness. For marbling, the correlation with intramuscular fat content was used.

5.0 PROJECT OUTCOMES AND RESULTS

The project had 4 defined outputs:

1. An accurate and objective evaluation of Australian beef carcass quality assessment using the TenderSpec™ Beef Classification System.

2. Documentation of the capability of the TenderSpec™ Beef Classification System to forecast beef tenderness class.

3. Establishment of the relationship between marbling score determined by the TenderSpec™ beef tenderness classification system and intramuscular fat content within the ribeye.

4. Archived data to facilitate subsequent optimization of the TenderSpec™ Beef Classification System for Australia.

The following sub-sections present the project outcomes/results/discussions based on the project objectives.

5.1 Objective 1 – Evaluation of beef tenderness using the TenderSpec™ Beef Classification system

5.1.1 Distribution of Measured Shear Force Values

The distribution of mean shear force (in kg) is shown in Figure 7.

A challenge occurs when trying to translate these values to U.S. values because the shear force protocols do not match. For example, in the U.S., Warner-Bratzler shear force is the most common scientific methodology employed to objectively assess cooked beef tenderness. The method entails shearing a series of cylindrical cores (with a cross-sectional area of 1.27 cm^2) removed from a cooked, cooled steak. In contrast, the Australian method is to shear a series of rectangular samples with cross-sectional areas of 1.0 cm^2. The values cannot simply be adjusted based on the difference in cross-sectional area as the force-deformation curves are different for cylindrical versus rectangular samples. This means we cannot simply use U.S. cutoffs to identify tender samples.

Using our proprietary data, approximately 80% of the population of U.S. beef would qualify for Tender and about 20% would remain Uncertified. We applied this same proportion in establishing a shear force cutoff between the categories. With rounding, the result is that Australian carcasses with a shear force less than or equal to 4.0 kg are classified as Tender. In this study, 17.5% of the samples did not qualify as tender.

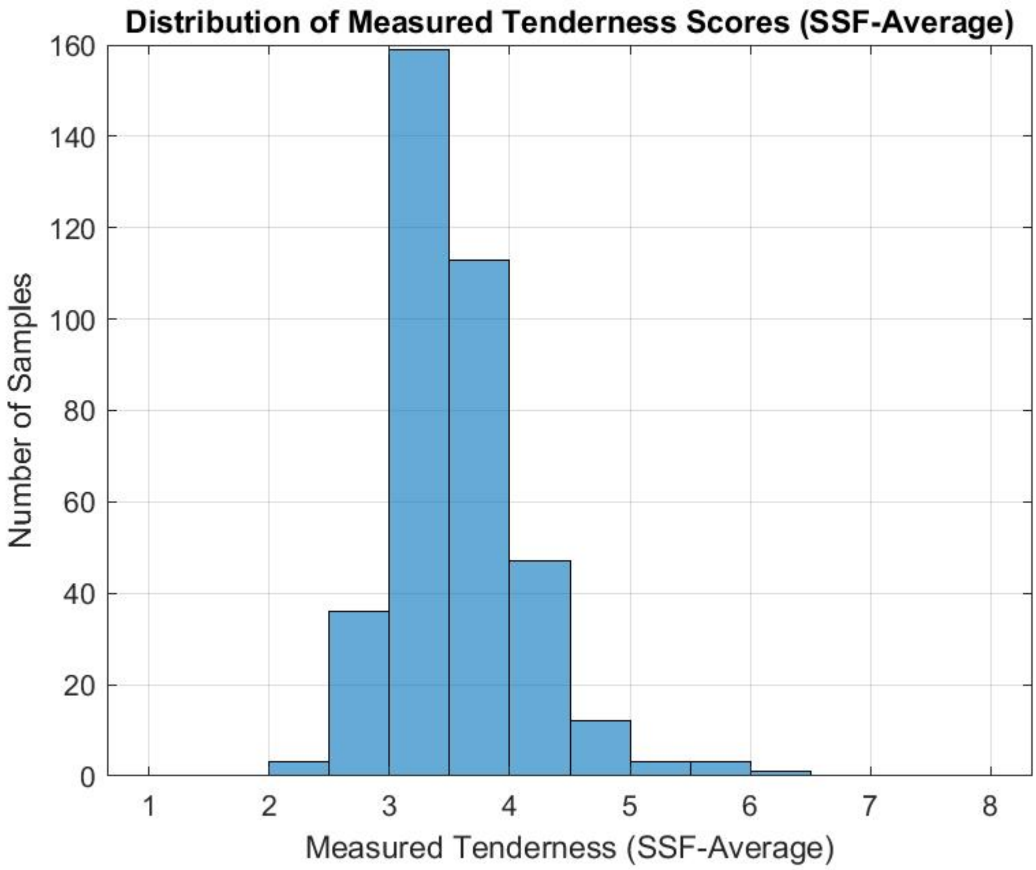


Figure 7. Tenderness distribution of beef steak samples aged 14 d (never frozen).

For purposes of data characterization, the mean of the two shear force values was calculated.

5.1.2 Distribution of Measured Shear Force Values by Gender, Use or Absence of Tenderstretch, and Breed

There were three main ways to categorize carcasses for the purposes of describing their tenderness character – gender, use or absence of Tenderstretch, and breed type (Tables 1, 2).

These results are supported by the literature. Females have been shown by Choat et al. (2006) to produce less tender meat than steers. The benefits of Tenderstretch to longissimus muscle -

tenderness were first reported in the 1970's by Orts et al. (1971), and many others have documented the tenderness benefits since that time (Greenwood et al., 2013; Smith et al., 1979). Phelps et al. (2017) have shown that an increase in *Bos indicus* breeding is associated with a decrease in tenderness. In this study, females had higher shear force values, slightly higher variation in shear force, and fewer carcasses in the upper tenderness category. Similarly, the benefits of Tenderstretch are evident, with lower shear force values, lower shear force variation, and a higher proportion of carcasses in the Tender category (90.0% vs 78.5%). Cattle with less than 50% *Bos indicus* breeding had more tender carcasses (84-88%) than cattle with 50% or more of *Bos indicus* breeding (66-75%).

Table 1. Distribution of shear force sample numbers across breed groups and suspension methods.

Suspension method	Estimated % *Bos indicus* 0%	25%	50%	75%	Total
Achilles	135	31	38	42	246
Tenderstretch	88	25	12	5	130
Total	223	56	50	47	376

Table 2. Shear force values described by gender, use or absence of Tenderstretch, and breed type.

Trait	Male	Female		
N	128	190		
Shear force, kg	3.41	3.60		
Shear force, std. dev.	0.44	0.57		
Tender %	90.6	78.4		
Uncertified tenderness, %	9.4	21.6		
	Achilles suspension	Tenderstretch suspension		
N	247	130		
Shear force, kg	3.62	3.43		
Shear force, std. dev.	0.57	0.45		
Tender %	78.5	90.0		
Uncertified tenderness, %	21.5	10.0		
	Estimated % Bos indicus			
	0%	25%	50%	75%
N	223	56	50	47
Shear force, kg	3.49	3.44	3.75	3.75
Shear force, std. dev.	0.46	0.54	0.66	0.59
Tender %	87.9	83.9	66.0	74.5
Uncertified tenderness, %	12.1	16.1	34.0	25.5

5.1.3 Repeatability of Measured Shear Force

Variation between the two steaks of a given sample creates problems when trying to evaluate accuracy of tenderness classification. Shear force values from duplicate steaks did not always agree. For example, the correlation between one steak and the adjacent steak taken from the same loin was just 0.59 (Figure 8).

These results are similar to our own proprietary data. In one of our studies, the correlation of slice shear force values between two steaks from the same sample was 0.70. While this type of variation in measurement of shear force is common, it makes the assessment of a tenderness classification technology difficult to determine. Stated simply, how can one evaluate a technology when the actual tenderness class is uncertain? At what point are the errors attributable to the technology and at what point are the errors in classification due to the inherent uncertainty of the true tenderness class? This makes it difficult to assess performance of the TenderSpec™ Beef Classification System when the "true" classification of the beef is uncertain. To correct for this, samples were included in the instrument assessment only when the two shear force values were within 0.6 kg of each other and when the shear force value of one steak would place the beef in the same tenderness category as the tenderness value of the second steak.

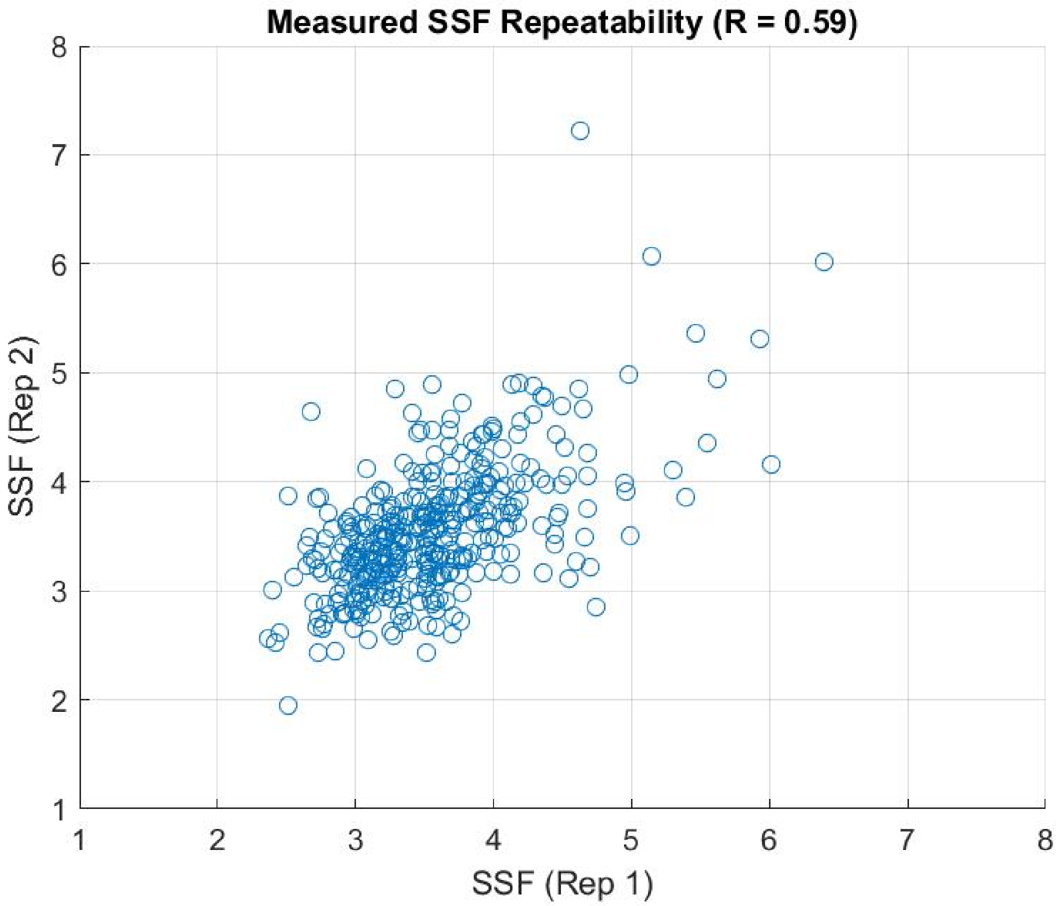


Figure 8. Repeatability of shear force from two adjacent steaks.

Data from the images were used to project tenderness class using our proprietary algorithm.

5.1.4 Accuracy of the TenderSpec™ Beef Classification System in Predicting Tenderness

The TenderSpec™ Beef Classification System is set to identify beef that can be certified as Tender. There were 255 samples which met the criteria for inclusion in the data set to evaluate performance of the TenderSpec™ Beef Classification System. The system identified 217 as Tender, of which 202 measured Tender. This represents a certification accuracy of this population subset of 93.1%. With a sample size of 255, the Z-statistic reveals this technology is accurate at 95% for the total population. In other words, a sample identified as Tender by the TenderSpec™ Beef Classification System measures tender with 95% accuracy. Notably, the TenderSpec™ Beef Classification System was able to certify 85.1% of the population as tender.

It is possible to have high certification accuracy by only certifying a small portion of the population. That is, you can be so conservative in identifying tender carcasses that many others are left behind in order to ensure those certified as Tender actually meet the criterion. It is notable, then, that 85% of the sample was certified as Tender. This means the TenderSpec™ Beef Classification System is capable of accurately identifying most of the tender carcasses with a high degree of accuracy. Some carcasses may be "likely" to be tender, but do not meet the strict criteria to be included the in the certified tender portion of the population, and are therefore not certified.

5.2 Objective 2 – Relate marbling scores obtained by the TenderSpec™ Beef Classification system to intramuscular fat

The population distribution of IMF content is shown in Figure 9. The overall mean was 3.70% fat and the standard deviation was 1.49. Various scientists have reported the IMF content of beef with a Slight amount of marbling (the marbling amount required for the USDA Select grade) was 3.43% (Savell et al., 1986), 4.64% (Garcia et al, 2006), 2.6% (Moore et al., 2010), and 3.09% (Dow et al., 2011). Those same authors, respectively, reported IMF content for Small marbling (the lower third of marbling required for the USDA Choice grade) to be 4.99, 6.55, 5.2, and 4.48%. It's clear that most of the cattle in this study would be classified in the USDA Select grade, with a few in the lower third of the USDA Choice grade.

This is a rather narrow IMF fat range on which to evaluate the by the TenderSpec™ Beef Classification System. The system predicts marbling, not IMF, so the relationship between predicted marbling and IMF is presented in Figure 10. The correlation was 0.72. This is superior to the correlation between MSA marbling score and IMF, which was 0.65.

Using a much broader distribution of samples, Moore et al. (2010) reported a correlation between IMF% and visually-assessed marbling score of 0.87 while Dow et al. (2011) found a correlation of 0.93. It should be emphasized these correlations reported in the literature are based on actual marbling scores, not predicted marbling scores. A small drop in correlation is to be expected when predicted marbling scores from a population skewed toward low IMF are used. Using internal proprietary data, we have shown that the TenderSpec™ Beef Classification System meets the USDA requirement for accuracy for predicted marbling scores.

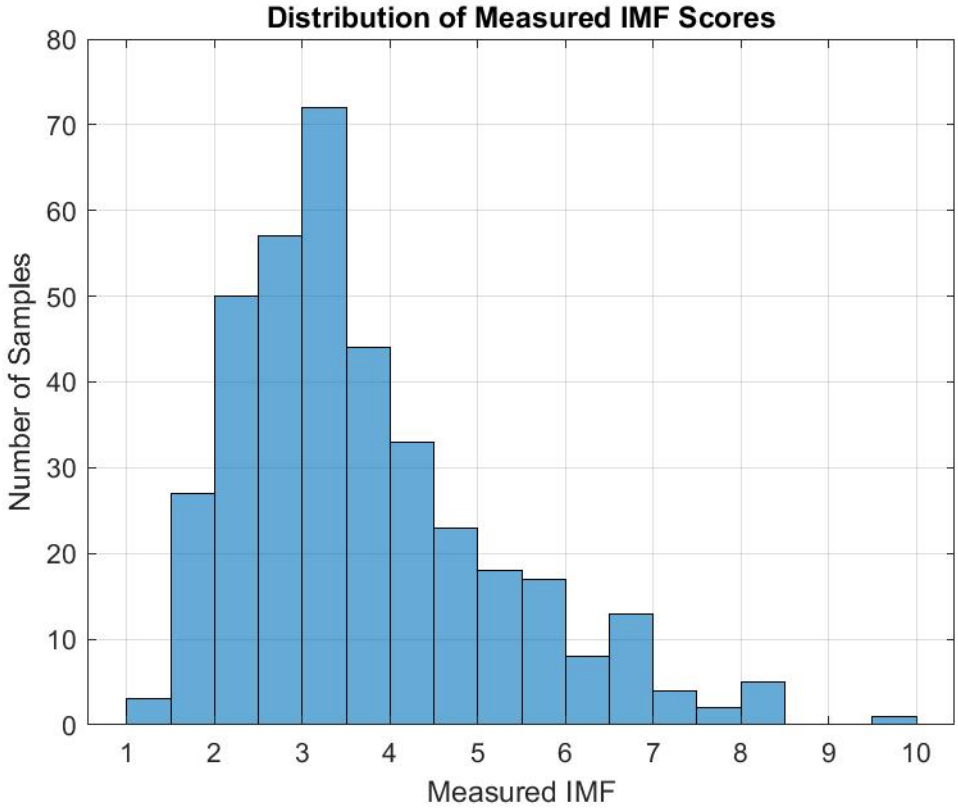


Figure 9. Distribution of intramuscular fat content among the tenderness samples.

For comparison, the correlation between MSA Marbling and IMF was determined (Figure 11). The relationship with IMF was lower than that found with marbling from the TenderSpec™ Beef Classification System. This indicates is sufficiently accurate with IMF to meet or exceed current Australian grading practices.

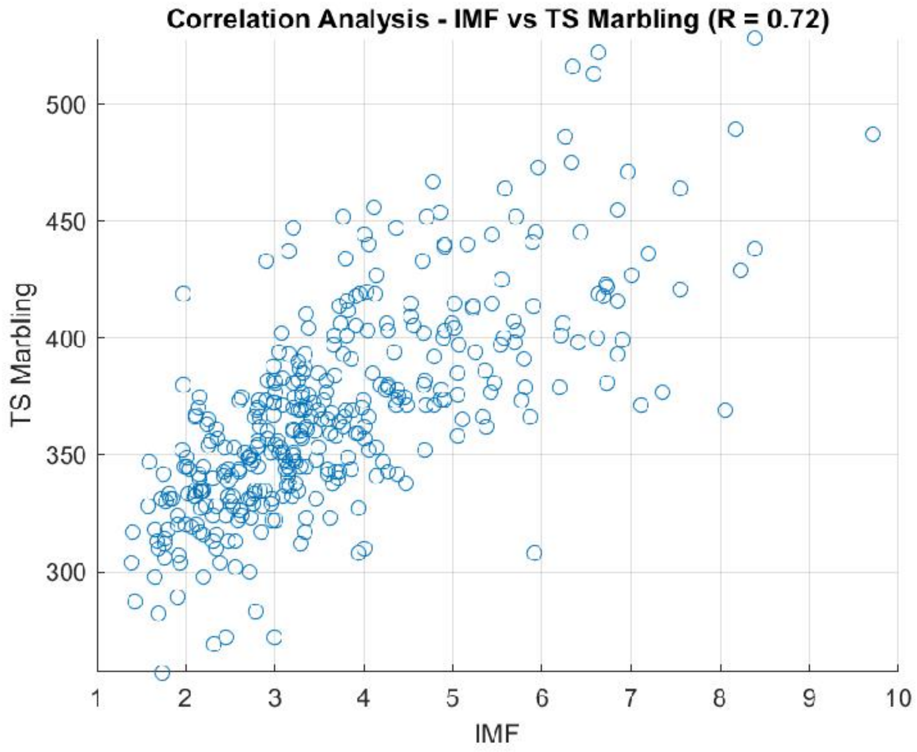


Figure 10. The relationship between intramuscular fat content (IMF) and predicted marbling score.

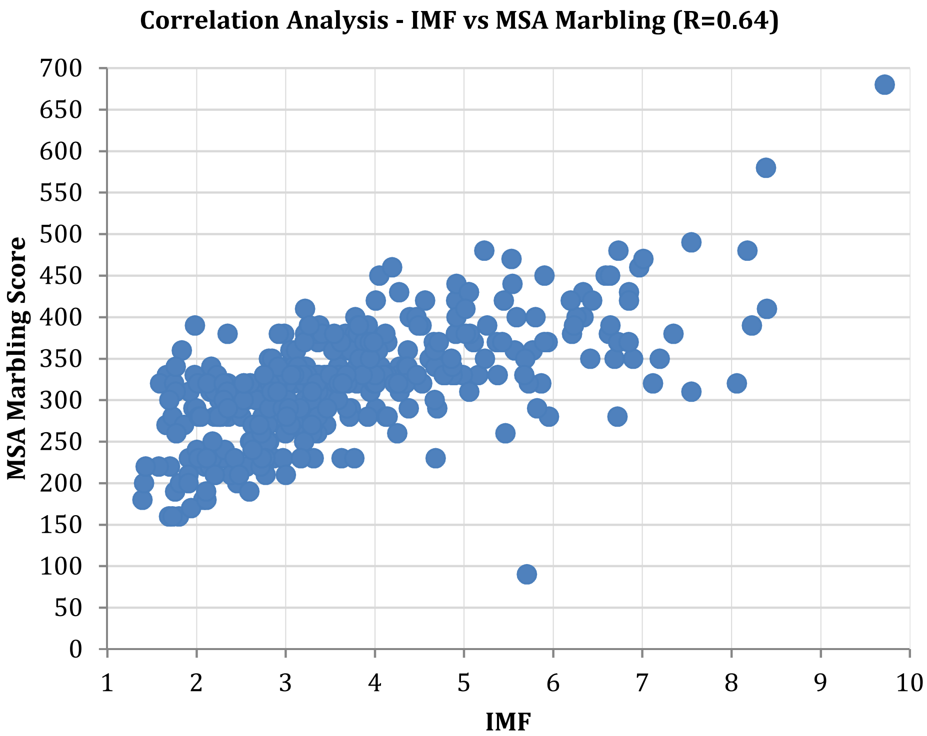


Figure 11. The relationship between intramuscular fat content and MSA marbling score.

5.3 Additional Analyses, Results, and Discussions

Although not a part of the project, we undertook to compare predictions from the TenderSpec^{TM} Beef Classification System to MSA data that were collected.

It should be noted that there are a multitude of reasons why algorithms established for U.S. cattle do not perform at the same level when applied to Australian cattle. (None of the algorithms were optimized for the Australian data we collected. This remains a potential direction of future effort.) Some of the reasons include:

Breed mix – *Bos indicus* breeding is more prevalent and of a higher percentage than commonly found in the U.S. The TenderSpec^{TM} Beef Classification System was calibrated against cattle that were mostly *Bos taurus.*

Carcass Weight – The average carcass weight in the U.S. is approximately 400 kg. The mean weight for this test of Australian cattle was 203 kg. This likely alters the chilling rate and slows the rate of rigor development – meaning tenderness could have been affected. (On the other hand, use of electrical stimulation may have counteracted this effect.)

Electrical Stimulation – The Australian meat plant had a more advanced electrical stimulation system in place than most U.S. plants. In fact, none of the large U.S. plants use electrical stimulation for tenderness purposes.

Tenderstretch – This carcass suspension method is not used in the U.S.

Chilling time – Many U.S. carcasses are chilled 48 hours before ribbing and grading. At a minimum, they would have been chilled a full 24 hours. In this plant, chilling was often less than 18 hours and sides were often ribbed after just 12-14 hours of chilling. In some cases, the longissimus muscle had contracted away from the cut surface. This may impact tenderness, meat quality, and the ribeye surface to be imaged.

Carcass temperature – As a consequence of the chilling time and chiller temperature, the carcasses were warmer when scanned than in the U.S.

Fat thickness – Australian cattle are substantially leaner, with less subcutaneous fat, than those in the U.S. This provides a narrower range of fat thickness than we normally see.

Ribbing location – The Australian carcasses we sampled were ribbed caudal or to the 13th rib. U.S. cattle are ribbed between the 12th and 13th ribs, giving a slightly different cut surface to evaluate. Also, ribbing with a saw creates a rough surface that is undesirable for quality evaluation.

Lower marbling – As noted earlier, the intramuscular fat content of Australian cattle is much lower than the U.S. This resulted in a leaner population with which to evaluate marbling prediction.

Smaller ribeyes – The lighter carcass weights meant the lean muscle area was much smaller. The Australian mean loin muscle area was 73 cm squared while the mean value in the U.S. is about 90 cm squared.

Cooking method - The cooking method for tenderness measurement (water bath immersion) is different that the U.S. method of grill cookery.

Shear force methodology – The Australian procedure is different than the slice shear force methodology (and different than the Warner-Bratzler shear force methodology) used in the U.S.

Despite these differences, we found fairly good agreement between predictions from the TenderSpec™ Beef Classification System and the data provided through MSA.

Table 4. Correlation coefficients between predictions by the TenderSpec™ Beef Classification System and MSA data.

TS Marbling vs MSA Marbling	0.64
TS LMA vs MSA LMA	0.64
TS fat thickness vs MSA fat thickness	0.71

These relationships can be optimized by further training the TenderSpec™ Beef Classification System and refining the algorithms. One challenge with all three relationships is the relatively narrow range and skewed distribution of the test sample for marbling, LMA, and fat thickness.

6.0 DISCUSSION

The discussion is included above with the results/outcomes.

7.0 CONCLUSIONS/RECOMMENDATIONS

This research has shown that the TenderSpec™ Beef Classification System is capable of classifying beef carcasses into certified Tender and Uncertified classes with 95% accuracy. The instrument predicts USDA marbling scores which are more highly related to intramuscular fat than MSA marbling scores in this study. Application of this technology in Australian beef plants has the capacity to benefit producers, the domestic market, and global competitiveness.

The current project was established to evaluate our technology against Australian cattle. A database now exists to facilitate development and optimization of algorithms for the Australian cattle population. This initiative could include marbling, and other traits collected with the MSA system. Thus, with modest additional support it would be possible to expand the project to optimizing the technology for Australia.

It is recommended to fund development of the algorithms straightaway. In the meantime, the system can perform well in the Australian market.

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9.0 APPENDICES

The data set will be sent electronically.