Final report

Camera grading for lamb meat quality to enable MSA Mark II cuts-based lamb grading

Project code:	V.TEC.1715
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Abstract

Intramuscular fat (IMF) is a key driver of lamb eating quality with the ability to grade carcases based on Meat Standards Australia eating quality dependant on the implementation of accurate measurements including IMF and lean meat yield. At the inception of this project there were no technologies available for measuring IMF at line speed in commercial abattoirs. This project explored the use of a hyperspectral imaging (HSI) camera system to predict the IMF in lamb meat 24 hours postmortem (at entry to the boning room). The line scan modality, high rate of data acquisition and non-contact operation of HSI devices make them advantageous to use within the meat processing industry. This led to the installation of an HSI camera system onto the Scott Automation & Robotics LEAP system at the JBS Brooklyn abattoir. This project reports the development of the camera system, on-line installation onto the Scott LEAP system and then validation testing against chemical IMF (198 samples) at line speed. Using the current statistical prediction model (based on extensive testing in New Zealand) the predictive accuracy would have been sufficient to gain AUS-MEAT accreditation from 2-6 IMF%, but with underprediction about 6%. The prediction model will be updated to improve the prediction of lamb with higher IMF followed by further validation testing against chemical IMF. Final implementation of the MSA Mark II cut x cook prediction model needs operational hook tracking so as to connect IMF, lean meat yield from DEXA and HCW data which can then be used for developing new elite lamb brands based on eating quality, as well as detailed producer feedback.

Executive summary

Intramuscular fat (IMF) has previously been identified as a strong positive contributor to lamb eating quality and is part of the new Meat Standards Australia (MSA) Mark II cut x cook eating quality prediction model. At the time this project was initiated there were no technologies available to measure IMF on-line in commercial abattoirs. Previous research has shown the ability to include hyperspectral imaging (HSI) devices on-line to measure a number of meat quality traits, including IMF, with good precision and accuracy. The ability for HSI devices to provide rapid, non-contact data acquisition make them appealing to the meat industry.

The objective of this project was to predict the IMF of lamb carcases 24 h post-mortem in a commercial processing plant using an automated HSI camera system attached to the Scotts LEAP system and link this data to DEXA lean meat yield and HCW in order to implement the new MSA Mark II eating quality prediction model.

A HSI camera was incorporated into the Scott LEAP middle machine system, whereby when the saddle is stationary on the middle machine, the camera's field of view (FOV) moved across the surface of the loin collecting images, especially in the near infra-red (NIR) range, that can be used to predict the IMF content. AgResearch (New Zealand) commissioned the HSI camera system, including loading of the Clarospec software for IMF prediction. After desktop calibration trials in New Zealand, the HSI camera system was integrated with the Scott LEAP middle machine at JBS Brooklyn where a validation trial was conducted using 198 lamb carcases. After scanning by the HSI camera, a loin sample was collected from each carcase and assessed for IMF content via laboratory NIR calibrated to Soxhlet extraction.

The predictive ability of the HSI camera system was sufficient to meet AUS-MEAT accreditation requirements from 2-6 IMF%. As expected, the current model is underpredicting IMF at the higher end of the range. Thus, the current prediction model used to predict IMF will be updated using the data collected in this study to enhance future predictions of IMF. The MSA MQ4 score was predicted for the short loins that were scanned in this study using the MSA Mark II cut-based eating quality prediction model. The distribution of loins across the MQ4 range was similar for lab NIR IMF and HSI-predicted IMF, although a smaller range was exhibited when using the HSI-predicted IMF as a result of underpredicting at higher IMF levels. The predictions of eating quality clearly showed the ability of MSA to underpin elite eating quality lamb brands. For example, in the validation experiment approximately 30% of the short lions were predicted at 3* with the remainder as 4* or above.

The key outcome of this project was the installation, calibration and use of an on-line HSI camera to predict lamb IMF in an Australian commercial lamb processing plant. Integration of the DEXA and HSI systems, as well as hook tracking, are essential to tracking of products through the boning room to segregate products based on individual value (weight and MSA eating quality) and to provide feedback on LMY, IMF and MSA index of individual carcases to producers. This feedback will also assist producers to make informed production decisions.

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1. Background

Eating quality of sheepmeat is a fundamental factor impacting consumer demand and accordingly a key goal of the Australian sheep industry is to improve the eating experience of lamb consumers (Pethick et al., 2006). To achieve this, an understanding of how critical control factors along the supply chain impact eating quality variation is required (Pethick et al., 2015) and have previously been reviewed by Pannier et al. (2018). Of these factors, intramuscular fat (IMF) is a very important element. IMF is known to be a strong driver of consumer-perceived lamb eating quality, with a positive association with all sensory traits (Hopkins et al., 2006; Lambe et al., 2017; Pannier et al., 2014). Therefore, animals with higher IMF levels will produce meat that is more acceptable to Australian and international consumers.

The current Meat Standards Australia (MSA) pathways system for sheepmeat offers a quality management program with best-practice guidelines in place for pre- and post-slaughter procedures (Bonny et al., 2018). However, extensive variation remains in eating quality of Australian lamb (Pannier et al., 2014), as a result of the system not accounting for individual objective carcase measurements except for hot carcase weight (HCWT) and a single measure of fatness (fat score). Although both traits are easily measured, they have minimal effect on eating quality, and hence cannot be used to segregate carcases based on predicted differences in quality grades. Furthermore, as the accurate prediction of individual cut weights from objective measurements of whole carcase lean meat yield (LMY) becomes commercially available (Gardner et al., 2018), an objective measurement of eating quality is critical to balance the negative association between these traits (Pannier et al., 2018; Pannier et al., 2014). Hence, development of an objective device to predict IMF of Australian lamb in on-line conditions is essential for the commercial uptake of MSA Mk II, a cut-based eating quality prediction model which uses IMF, lean meat yield (LMY), carcase weight (HCW), electrical stimulation and aging to predict the eating quality of 9 cut x cook combinations (Pethick et al., 2015).

Previous research has shown that IMF of the M. *longissimus lumborum* (loin) is correlated to muscles within the fore- and hind-sections of the lamb carcase (Anderson et al., 2015). This supports the use of a single measurement of IMF from the loin to be used to predict the eating quality of other muscles in the carcase within the updated MSA Mk II system. To capture an IMF measure, many technologies are currently being trialled, including hyperspectral imaging (HSI) devices.

HSI cameras are becoming increasingly appealing within the meat industry due to their rapid assessment and non-contact data acquisition, as well as their ability to capture data from within both the spectral and spatial dimensions (Jia et al., 2022). These features of HSI devices allow for the technology to be automated within processing plants. HSI devices can provide a non-destructive assessment of meat quality and previous research has shown the prediction of lamb loin IMF with good precision and accuracy (Craigie et al., 2017).

HSI IMF predictions need to be linked to individual carcase data (HCW, LMY) to allow for trading based on eating quality predicted by the MSA Mk II system. Hence the objective of this project was to deliver a HSI system that can reliably predict the IMF of lamb carcases at 24 h post-mortem in an automated, commercial processing plant.

2. Objectives

The objectives of the project were:

- Utilise camera grading to predict intramuscular fat (IMF), ultimate pH (pHu), eye muscle area, C-fat depth and GR tissue depth.
- Combine the traits of IMF, lean meat yield (LMY) derived from DEXA measurement, hot carcase weight (HCW) and sire type (Merino, Border Leicester and Terminal) to estimate the MSA eating scores of selected cuts.
- Develop a real time solution to physically mark loins and associated legs with an eating quality score greater than a predetermined threshold.
- Connect the carcase grading data and MSA score to the abattoir database to enable producer feedback of the grading data.

3. Methodology

3.1 Camera design and installation

In this project a HSI camera was incorporated into the Scott LEAP middle machine system.

Due to the nature of implementing a HSI camera into a commercial plant at chain speed, many considerations needed to be taken into account in order to select an appropriate device. Firstly, the camera needed to be able to operate at the optimal speed of operation (10 carcases per minute). Secondly, the loin surface was required to be scanned in a stationary position early in the process of the middle machine when the shortloin primal remained stationary for 1.1 seconds. Whilst the shortloin remained stationary, the camera's field of view (FOV) needed to move across the loin surface to collect the images. As moving the whole camera robotically was not considered a viable engineering option, the preferred technology was to incorporate a moving mirror system placed in front of the camera. Thus, the mirror moved the camera's FOV across the loin. A push broom or line camera, where the object is imaged as a series of lines across its surface, was considered the most appropriate camera. Other considerations included the area to be measured (50 mm x 50 mm for a single loin) and that the camera could generate images of the optimal wavelength range of ~900 nm to ~1700 nm. AgResearch (New Zealand) were consulted for selection of an appropriate HSI camera.

The final camera selected for imaging was the Specim FX17e FOV 12o F#1.7 HSI machine purchased from Adept Turnkey. This was connected to a rotating mirror (created by Startek Australia, Melbourne) and installed inside an abattoir-compliant water proof box designed by Scott Automation & Robotics. The below parameters were negotiated with Adept Turnkey based on the AgResearch prototype of this same camera:

- Spectral range of 900 nm – 1700 nm with high spectral resolution (NIR range being crucial)
- High spatial resolution (640 pixels)
- High imaging speed (~500 FPS)
- Standard type hardware interface (GigE Ethernet type)
- Capable of industrial environment operation (processing plant boning room temperature <10 °C)
- 500 nm scanning width when at a distance of 500 mm from the imaging surface (53-degree FOV lens)

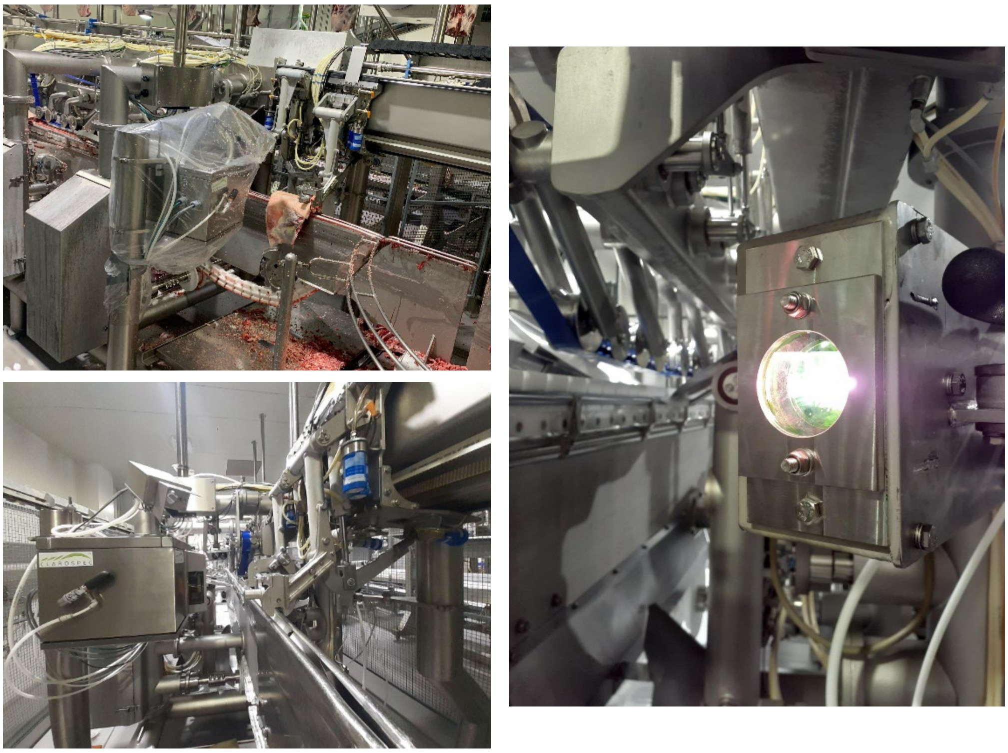
- Software Development Kit (SDK) for integrating the Specim FX17e data capture and control into Clarospec software

The box system, incorporating the camera and mirror, were commissioned by AgResearch, Christchurch (New Zealand). This included loading the Clarospec software onto the device and trialling the system in real-time using freeze/thawed bone-in shortloins to develop the initial calibration data (desktop calibration). Bone-in shortloins were provided by Murdoch University (n = 30) from the Katanning MLA Resource Flock and AgResearch (n = 30). Shortloins were selected based on a range of visual IMF (high and low), with chemical IMF ranging from 2.19 to 7.47 %. The HSI camera system destined for the Scotts LEAP middle machine was tested against a similar system developed by AgResearch whereby the same statistical prediction software was used in both systems (Clarospec). The results of this calibration have previously been reported (Moyes et al., 2022a, 2022b) and showed the system could measure IMF with good accuracy and that interfering factors such as bone smear were not hugely problematic.

3.1.1 HSI camera on-line functionality

Integration of the HSI camera system with the Scott LEAP middle machine at JBS Brooklyn, Melbourne, occurred in June 2022 (Fig. 1). Installation of the device included two additional lighting arrangements to compensate for spectral reflectance reported during the desktop calibration trial (Moyes et al., 2022b). Initial testing showed that there was a sufficient amount of lighting available, and the camera's focus was optimal in the commercial setting.

Figure 1. Photos of the camera housing (containing the camera) and two additional lights installed at JBS Brooklyn, Melbourne.



Once the image has been captured, the HSI camera system processes the image through a third-party Dynamic-link library (Clarospec software, AgResearch) whereby the statistical model to predict IMF is applied. This process must be completed before the next shortloin is presented to the camera, approximately five seconds later. At the completion of the prediction, the output is transferred to a database where the pixel count, average spectrum, IMF prediction and image quality parameters are associated with the correct carcase.

A set of Standard Operating Procedures for the day-to-day operation of the camera system by JBS staff has been created for when online commercial use of the device begins. This includes the white tile calibration and turning on of the device, as well as the cleaning procedure and spare parts inventory.

3.1.2 Challenges of commercial integration

Upon final testing of the camera and mirror system mechanics prior to calibration, it was found that the motor was not operating smoothly and, as a result, the final image taken would look jagged. Adding weight to the mirror corrected this issue and thus a replacement, heavier mirror was constructed out of Grade 316 steel by Startek.

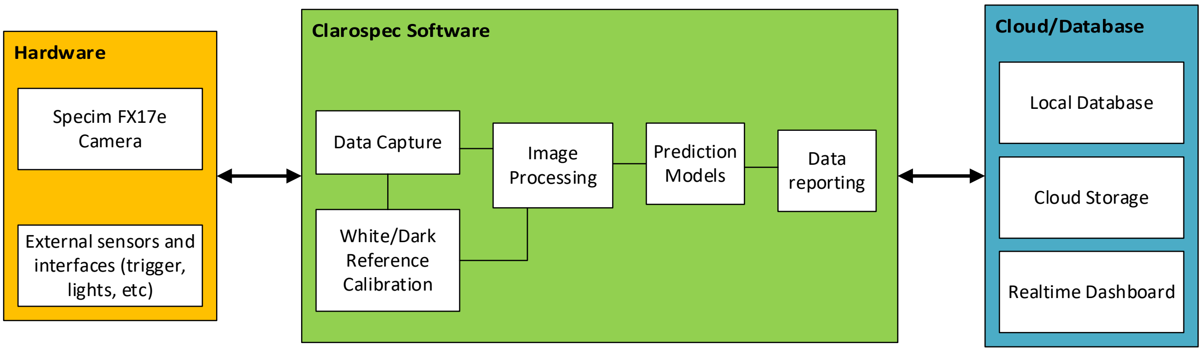
During the desktop calibration trial, a spectral reflectance issue was encountered due to insufficient lighting. To overcome this, the exposure length was increased from 2ms to 8ms during the trial and hence the imaging time was longer than the allocated on second required for on-line incorporation with the middle machine system. Further testing by AgResearch on approximately 800 lamb saddles evaluated the image of scanning at 2ms on the spectral reflectance on the images. It was concluded that two additional lights would be added to the system to reduce spectral reflectance and thus allow the system to operate at the required speed. In addition, during the desktop calibration trial, there was an issue with the mirror stability, and this has been fixed by Adept Turnkey.

Once installed on the middle machine at JBS Brooklyn, some vibration issues were identified due to the structural integrity of one of the posts. This was addressed by adding a brace set to the structure however this did not fully eliminate the issue. Fortunately, the current image processing does not appear to be compromised to a great extent by the vibrations, however, they may severely impact the addition of new features such as loin size/shape measurements and fat cap thickness. The primary concern of the vibrations is the wear and tear on the hardware as the structure is not designed to operate under constant vibration, and there is particular concern about the mirror assembly. It is not known how/when/if this will fail due to the vibrations if they are not removed.

3.1.3 Clarospec software

Clarospec software enables integration of four components of the system in one package for real-time prediction of meat quality attributes (Fig. 2). These components are hardware, image processing and handling software, prediction models and data. It is important that the system operates in real-time so that interventions can be made as required (e.g., active calibration system, environmental monitoring including but not limited to ambient temperature, light, humidity and product temperature, live feed to web for remote monitoring and active notification/alert system).

Figure 2. Clarospec software framework, integration with other modules and internal module architecture.



The Clarospec software was designed and developed to be a modular software. Therefore, different types of cameras, image processing algorithms and prediction models could be added as modules instead of being hard coded into the software. As part of the development of the Clarospec system, a set of specifications were developed for the procurement of the Specim FX17e with a 53-degree FOV lens and the Specim FX16e FOV 12o F#1.7 to allow for stand-alone modular configuration and full integration of this device with the middle machine.

The Specim FX17e comes with an off-the-shelf basic software (LUMO Recorder) installed. This software provides basic camera operations for imaging, including calibration by dark and white tile, hypercube image capture, frame rate and exposure rate control. These provided features of the LUMO Recorder were integrated with the Clarospec software (developed in C#. Net programming language).

Statistical analysis (including T2 and Q statistics) are performed in real-time for every prediction for quality assessment of the scanned meat data. The prediction results are reported in real-time on the main software HMI screen stored in the local database and transferred to cloud storage (Azure). If required, other data such as hypercube images can be transferred to the cloud later in the day as these files are large and cannot be transferred in real-time. The cloud system enables the visualisation and storage of real-time prediction results, virtual workstation for software upgrade and model tests and validations, and storage of big data generated such as hypercube images.

3.2 Carcase selection and image collection for calibration/validation

Sample collection for the 1st calibration/validation experiment aimed to obtain loins with varying levels of intramuscular fat as to represent the Australian lamb flock. Carcases were sourced at the instillation location of the HSI camera, the JBS abattoir in Brooklyn, Victoria. On a single day, a total of 234 lamb carcases were selected in the chillers (24 h post-slaughter) based on hot carcase weight and fat score (Table 1). The mean HCWT was 28.0 kg (± 4.3 kg). Carcases were scanned via an on-line Dual Energy X-ray Absorptiometry (DEXA) system to determine LMY, and then split into forequarter, hindquarter, and saddle sections. The saddle section entered the Scott LEAP middle machine whereby the rack was removed. The saddle then passed by the HSI camera where an image was taken of the cranial end cut surface. Saddles were collected from the processing conveyor belt for collection of IMF samples.

Table 1. Number of lambs selected according to hot carcase weight and fat score

	Hot carcase weight (kg)		
Fat score	< 22	22 – 28	> 28
1	0	0	0
2	0	0	0
3	10	55	2
4	1	59	53
5	0	1	53
Mean hot carcase weight (kg)	21.1	25.0	31.9

3.3 Chemically determined IMF

After retrieval of saddles from the conveyor belts, the left loin was removed and denuded of external fat and epimysium. A 40 g sample from the cranial cut surface (imaged surface) was collected and placed in 50 ml tubes, frozen and transported to Murdoch University for chemical determination of IMF via laboratory NIR calibrated to a chloroform Soxhlet (Perry et al., 2001).

3.4 Statistical analysis

3.4.1 Pre-existing model

As a result of differences in genetic and production systems, IMF content of Australian and New Zealand lamb loins varies. In general, the Australian lamb industry has a much greater range (~1-10% IMF) and has a higher average (4.5%; Pannier et al., 2014) than New Zealand lambs (range ~1-6% IMF, average = 2.7%; Craigie et al., 2017a). To translate calibration performance and prediction models developed for HSI systems on New Zealand lamb samples to the Australian sheepmeat industry, a global calibration equation was developed using a partial least-squares regression (PLSR) analysis based on available spectral (collected at 24 h post-mortem) and wet chemistry data of lamb (n = 1229) and beef (n = 129) with an IMF content of up to 10% (Robert et al., 2021). Samples were collected over a range of years and flocks to capture IMF variation. The RMSE, SEP, bias and R^2 were used to determine the IMF% prediction performance and are shown in Table 2 for the calibration and validation. It is important to note that the bias is extremely low (as expected during modelling) and not representative of the real world. Future sampling under commercial conditions will primarily account for this.

Table 2. Calibration and validation performance of prediction equations developed within the Clarospec hyperspectral prediction software - data collected on M. *longissimus lumborum* from beef (n = 129) and lamb (n = 1229).

	n	R^2	RMSE	SEP	Bias
Calibration	904	0.82	0.49	0.49	
Validation	454	0.81	0.53	0.53	-0.01

Currently, the IMF prediction model from the HSI camera output is based on wet chemistry reference data determined using Gas Chromatography by Flame Ionisation Detection (GC-FID). As part of this trial, the model will be updated to predict the NIR/Soxhlet IMF%, which is the recognised method of the Australian Meat Language and Standards Committee.

3.4.2 Commercial validation trial

Validation performance was calculated using HSI data acquired in 2022. None of the scans for validation were included in the calibration model, therefore representing a fully independent validation test. For the relationship between actual versus device predicted IMF%, the R^2 and root meat squared error of the prediction (RMSEP) were used to report the precision, whereas the slope of the relationship between actual and predicted values and bias were used to report accuracy. Bias is defined as the difference between the actual and the predicted value at the mean of the predicted trait.

Following the trial, images and IMF% data will be used to update the existing prediction model.

4. Results and discussion

Of the 234 carcases selected, 198 carcasses and shortloins were imaged with the HSI camera system. From the carcasses selected, 34 were rejected following DEXA scanning and 2 saddles were rejected by the LEAP middle machine and thus were not imaged by the HSI camera. The raw data for objective carcase measurements of HCWT, lab-based IMF%, HSI camera predicted IMF% and DEXA LMY% values are summarised in Table 3.

Table 3. Mean (± SD) and range for hot carcase weight (HCWT), Hyperspectral camera predicted intramuscular fat (IMF), lean meat yield (LMY) and total carcase fat. Data are presented for 198 animals.

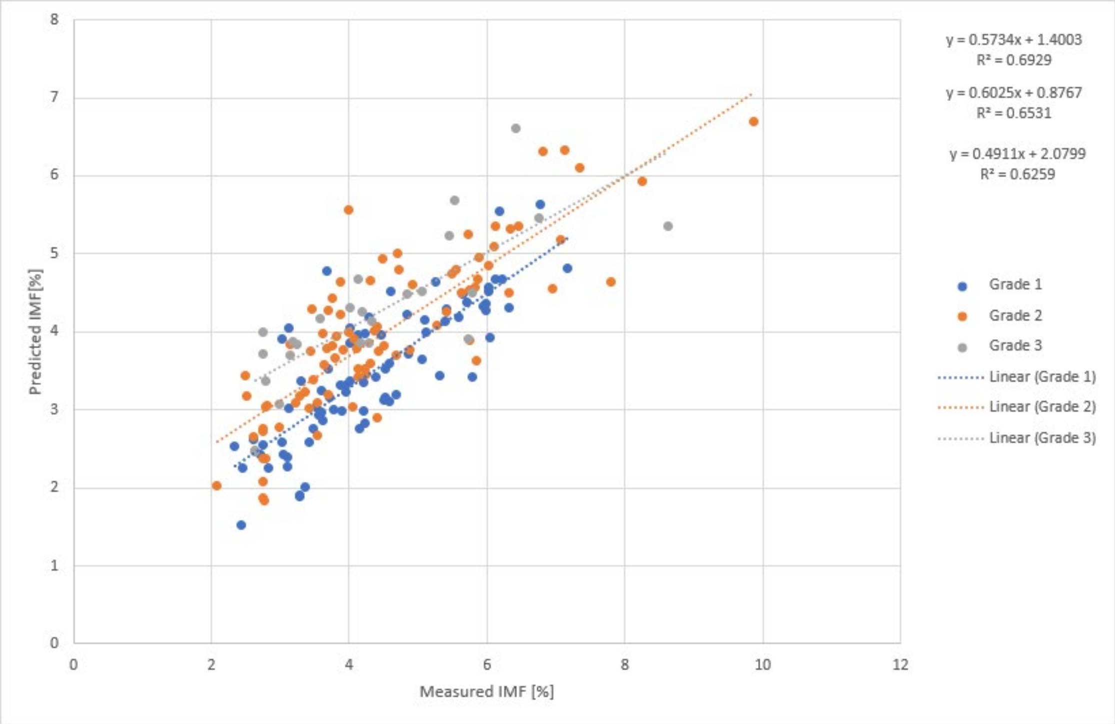
	Mean ± SD	Range
HCWT (kg)	27.6 ± 4.2	18.8 – 37.8
Lab-based IMF (%)	4.2 ± 2.6	2.1 – 9.9
HSI camera predicted IMF (%)	4.3 ± 1.0	2.0 – 6.6
LMY (%)	56.2 ± 6.5	38.3 – 71.0
Total carcase fat (%)	29.6 ± 9.0	9.0 – 54.4

4.1 Ability of LEAP HSI camera to predict IMF

Fig. 3 demonstrates the relationship between the predicted HSI camera and the lab-based IMF values. Each HSI image was given a subjective grade based on the quality of segmentation of the image (1 being best, 3 being worst). Fortunately, the image quality did not greatly alter the prediction (Figure 3). The variable segmentation is almost certainly associated vibration of the camera during the experiment and Scotts have since undertaken more adjustments to further reduce vibration.

As anticipated, the current model is underpredicting IMF, particularly at higher IMF levels due to the model being based on New Zealand sheep (Figure 3).

Figure 3. Scatterplot of the HSI camera predicted vs the actual IMF values of 195 Australian lamb loins, according to segmented grades



Further analysis, using all the data, was undertaken to understand how close the HSI camera system predicted IMF was to achieving AUS-MEAT accreditation using the 'Device Accreditation Analysis – IMF% Sheep Meat' app available on line at https://accreditationapps.shinyapps.io/Sheep_Meat_IMF_Percent_V4/.

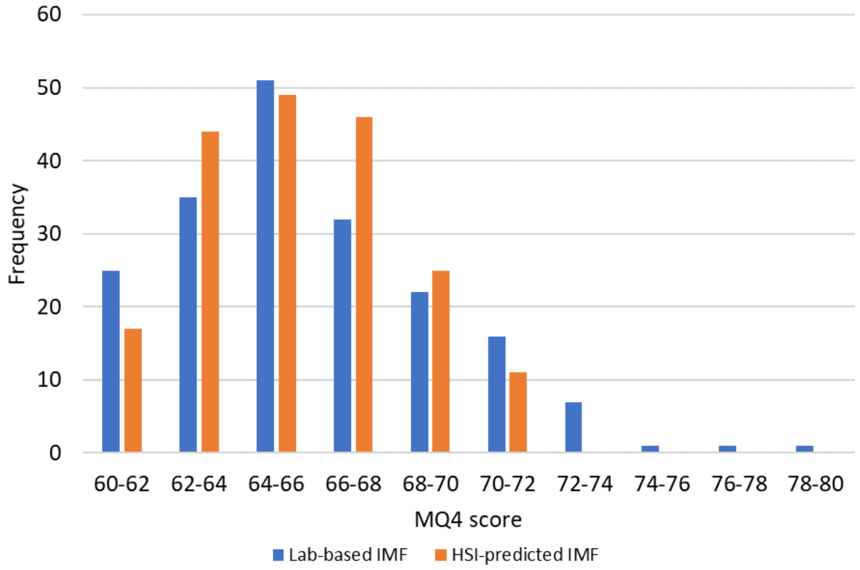
This experiment was not conducted as an AUS-MEAT accreditation, however, the predictions were sufficiently accurate to theoretically gain accreditation for an IMF range of 2-6%. There were only 28 observations with IMF above 6% and so the potential to test accreditation beyond 6% was not possible. In addition, it is also clear that the current Clarospec model underpredicts chemical IMF beyond 6%.

After this 1st calibration/validation run the new data from This experiment has been used to retrain the Clarospec prediction model (with poorly segmented grade 3 images removed). It is intended to run a further validation experiment, This time under a formal AUS-MEAT accreditation environment.

4.2 MSA grading of loins

The MSA composite meat quality score (MQ4) for the 9 cut x cook combinations was predicted using the IMF values (both chemical IMF and HSI predicted IMF), DEXA LMY and HCW. The frequency distribution of the MQ4 score for the short loins according to chemical IMF and HSI camera predicted IMF are shown in Fig. 4. The distribution of loins across the MQ4 range is similar, although the range of MSA predicted scores is less when utilising the predicted IMF values (Fig. 4). THIS is a further indicator of the current IMF prediction model underpredicting IMF at higher values. Updating of the current model using This dataset will aid in correcting This.

Figure 4. Frequency distribution of short loin MQ4 scores based on chemical and HSI predicted IMF values (with electrical stimulation, 5 days aging, MSA Mark II 2021 v2, draft1).



The predictions of eating quality clearly showed the ability of the MSA Mark II to underpin elite eating quality lamb brands (Figure 4). For example, in the validation experiment approximately 30% of the short lions were predicted at 3* with the remainder as 4* or above (MQ4 ≥ 64).

5. Conclusion

The first HSI system has been installed and is able to operate at chain speed within a commercial processing plant in Australia. The device is able to output an IMF prediction under commercial conditions, based on the pre-existing lamb IMF algorithm based on New Zealand lamb data as a reference. The current model being used to predict IMF is underpredicting particularly at higher IMF values due to the model being based on New Zealand sheep only, and as such the model will be updated using data from the JBS Brooklyn trial. Despite these limitations the results clearly show the potential of using objective measurement of IMF and LMY to predict the eating quality of lamb cuts and also to potential create higher grading company lamb brands.

5.1 Key findings

The first HSI system for measuring lamb IMF is now installed and has been used on-line in a commercial lamb processing plant in Australia.

A set of lamb saddles (validation dataset with a broad range of IMF) have been scanned through the system. Meat samples have been collected and sent for independent analysis of IMF and validation of the HSI technology. Results showed the device can meet AUS-MEAT accreditation for IMF between 2-6% but is underpredicting of IMF at higher levels of IMF. THIS will be accounted for in an update of the statistical model used to predict IMF from the HSI output.

5.2 Benefits to industry

Full integration of the DEXA (for LMY measurement) and HSI camera system (for IMF measurement) are essential to enable producer feedback of LMY and IMF on an individual carcass basis and the implementation of the new MSA Mark II model. This information is highly valuable to enable both price signalling to producers and feedback to enable informed decision-making regarding flock improvement. Full integration will also allow the development of methods to segregate lamb cuts based on MSA quality thresholds to underpin elite lamb brands. The current barrier at JBS Brooklyn is the lack of a functioning hook tracking system.

6. Future research and recommendations

- Vibration of floor causing noise in HSI images and additional wear and tear of hardware was an unexpected hurdle and needs monitoring.
- Functional hook tracking is essential for integration and operation of the HSI camera.
- Tracking of products through the boning room in order to segregate products based on MSA quality grades requires significant work and process-driven thinking once hook tracking is operational.
- A functional HSI camera operating at line speed offers the ability to undertake further research for the ability to measure new traits that may relate to consumer satisfaction, human health attributes and even provenance claims of lamb.

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