Final report

Translating intramuscular fat measurement technology to the sheepmeat industry

Project code: V.TEC.1726

Prepared by: Robert McLaughlin
Miniprobes Pty Ltd

Date published: 23 September 2024

PUBLISHED BY
Meat & Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

Intramuscular fat (IMF) is a key factor for achieving premium eating quality in lamb. A device capable of rapidly measuring the percentage of intramuscular fat (IMF%) in a hot carcase would enable meat processors to identify premium quality meat prior to chilling. This project has developed a new optical device to measure IMF in hot carcases.

The device is called an IMF needle. It consists of a fibre-optic probe encased within a small needle that scans the muscle as it is inserted into the carcase. This needle technology does not require any cuts to the carcase. Our device uses a standard medical imaging technology, optical coherence tomography, to acquire a high magnification image of the fat cells in the muscle. From this image, we are able to calculate IMF%.

This project has advanced the device from an early prototype to a working, portable unit that has undergone preliminary field trials in a commercial meat processing plant. The device can calculate an estimate of intramuscular fat within 3 seconds of scanning a carcase, with a mean absolute error of 0.68% against a chemical gold-standard measurement. Within this trial, 84% of our intramuscular fat estimates with found to be within 1% of the gold-standard value, and 98% were within 2% of the gold-standard. This exceeds the AUS-MEAT accreditation standards for IMF% in sheep therefore giving confidence the device will successfully achieve accreditation in a future trial.

Executive summary

Background

Consumers will pay more for quality meat. The major factor in eating quality is intramuscular fat. The task of assessing meat eating quality can be addressed by accurately measuring the percentage of intramuscular fat in the sheep carcase. This project is developing a new device to measure intramuscular fat in hot carcases in a meat processing plant.

Objectives

A previous MLA project (P.PSH.1244) identified a technology developed at The University of Adelaide with the potential to measure intramuscular fat. The objective of this current project has been to translate that technology, developing a prototype to establish technical feasibility, and undertaking field trials in a commercial meat processing plant. These objectives were successfully achieved.

Methodology

We developed a device consisting of a handpiece for scanning the carcase, and a console containing the core optics modules and a computer for analysis. The handpiece has 4 stainless steel needles, each needle containing two tiny fibre-optic probes the thickness of a human hair. As the needles are inserted into the carcase, they acquire a high-resolution image of the intramuscular fat. This image is analysed using artificial intelligence algorithms to automatically compute an estimate of the percentage of intramuscular fat. This prototype device was tested in a field trial at TFI Tamworth with 250 lambs from the MLA Resource flock and results were compared against a chemical gold-standard.

Results/key findings

The device produced estimates with a mean absolute error of 0.68 IMF%, a root mean squared error (RMSE) of 0.87 IMF% and an R^2 of 0.48. 84% of estimates were within 1% of the gold standard IMF% measurement. 98% of the estimates were within 2% of the gold standard IMF% measurement. This satisfies the accuracy required for accreditation within the meat industry by AUS-MEAT.

Benefits to industry

The development of a reliable device to measure meat eating quality in sheepmeat would allow processors and producers to extract greater value from their product. It would enable retailers to segment sheepmeat products based on eating quality, and provide a commercial differentiator for Australian exports to overseas markets. We estimate that this could generate an additional $173 million of value per year for the Australian sheepmeat industry.

Future research and recommendations

Further work will be required to complete translation and commercialisation of this device. MLA support will be critical to attract the necessary funding and also to accelerate industry adoption.

Acknowledgements

We wish to acknowledge the support of Meat & Livestock Australia, The Australian Meat Processor Corporation (AMPC), and The University of Adelaide for their assistance in making this work possible.

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1 Background

In this project, we are developing a new device to measure eating quality in lamb meat. Consumers will pay more for quality meat. Compared with MSA Grade 3 meat, consumers will pay an extra 50% and 100% for Grade 4 and 5 (highest quality) meat (Swan et al., 2015), but meat processors currently lack tools to allow them to exploit this opportunity.

Meat quality varies between individual sheep, so every lamb carcase needs to be tested. At present, there is a lack of commercially viable technologies to measure meat quality in a sheep carcase early in the processing workflow. Such a technology would allow meat processors to customise carcass handling, fabrication and individual cut marketing. It would also provide valuable feedback to sheep producers to optimise breeding and husbandry choices to produce premium meat animals.

The major factor in eating quality is intramuscular fat – tiny traces of oil in the muscle that make it juicy and tender (Hopkins et al., 2006, Pannier et al., 2014). The task of assessing meat eating quality can be addressed by accurately measuring the percentage of intramuscular fat in the sheep carcase.

This project builds upon research from University of Adelaide to develop an IMF needle. The needle consists of a highly miniaturised fibre-optic probe inside a metal needle 3mm diameter that is able to image muscle tissue structure using high resolution optical imaging. This is analysed by a neural network to automatically quantify the percentage of intramuscular fat and assess meat quality.

We have developed this technology into a handheld optical scanner capable of accurately measuring the percentage of intramuscular fat. The scanner has been designed for use in a meat processing plant. Measurements are performed on a hot lamb carcase (i.e. immediately after slaughter and before the meat has been chilled). This allows the meat processor to rapidly identify high quality lamb meat for sale as a premium product.

The funding for this MLA project was used to leverage additional support through the Cooperative Research Centres Project (CRC-P) scheme, managed by the Australian Government Department of Industry, Sciences, Energy and Resources. MLA funding was leveraged at a proportion of 2.5 to 1.

2 Objectives

This project describes the development of a device to measure intramuscular fat, and preliminary validation trials to assess the accuracy of the scanning technology. This has been demonstrated through the production of several prototype devices, and by conducting field trials in a commercial meat processing plant.

Specific objectives for the project are listed below:

1. Establish a team including hardware and software engineers, livestock researchers and meat scientists to successfully deliver the project.
2. Undertake initial carcase IMF scans and analysis to inform prototype design.
3. In collaboration with MLA project V.TEC 1723, design a scanner console and IMF scanning needles.
4. Complete a technical description document and construct one console and a set of IMF needles that satisfies design requirements.
5. Conduct field trials demonstrating technical feasibility, in which data is captured in a commercial meat processing environment using prototype system.
6. Conduct a trial capturing data in a meat processing environment at the rate at which carcases are processed during a typical production run using a commercial-demonstrator system.
7. Provide a final report describing a) field trial for performance and speed using a commercial demonstrator system, b) application to AMILSC for AUS-MEAT accreditation to measure IMF% in lamb.

Each of these objectives has been met successfully

3 Methodology

3.1 Device overview

The device consists of a handpiece with four stainless-steel needles, each needle containing two tiny fibre-optic imaging probes to analyse the meat. The handpiece is attached to a wall-mounted console that contains the necessary optical and electronic components. A photo of our prototype handpiece and the wall-mounted console is shown in Figure 1.

Figure 1. (left) Handpiece, comprising 4 needles to perform multiple measurements simultaneously. (right) Console that is connected to the handpiece, mounted on a stainless-steel pole.

As the needles are inserted into a hot carcase, each of the 8 fibre-optic probes (2 per needle) acquires a microscopic-scale image of the muscle structure. Figure 2 shows an example of a typical image acquired by one probe. This image displays a small section of the muscle up to a distance of 2mm away from the needle. Computer analysis software is able to identify the amount of fat within the muscle.

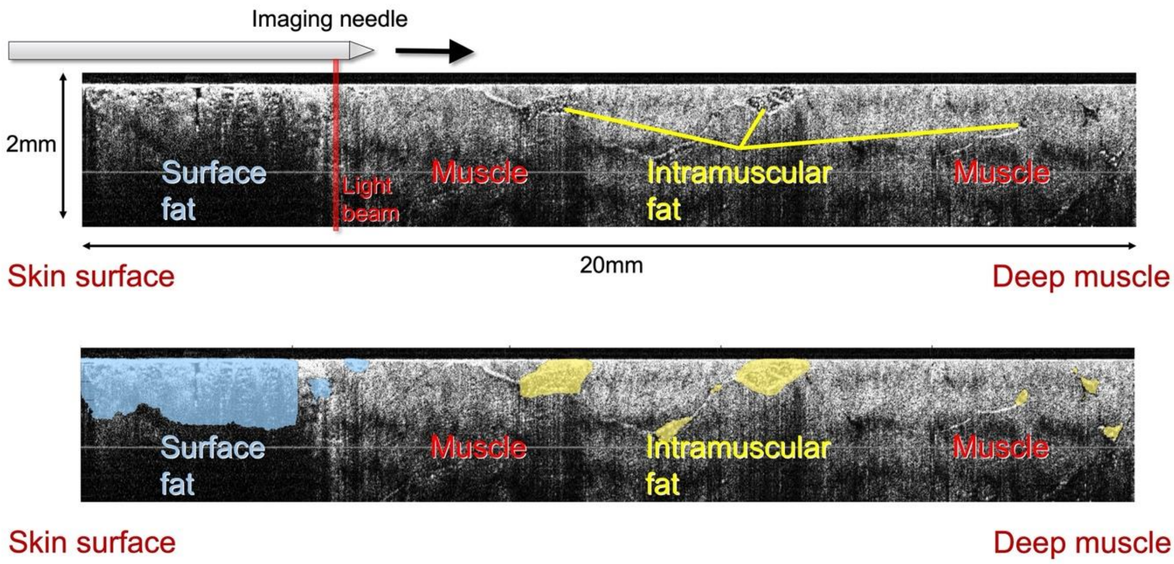

Figure 2. (top) IMF needle scan from a hot carcase. (bottom) Automatic image analysis with fat highlighted in yellow.

By automatically analysing these images with an artificial neural network algorithm, we are able to objectively quantify the percentage of intramuscular fat. The raw data is reconstructed and analysed using an artificial neural network based on a Feature Pyramid Network. This 5-layer pyramid network had 4.9 million parameters and was implemented using the MobileNetV3 encoder, which provided a good trade-off of high accuracy and rapid computation. The network was trained on data from 10,000 individual probe scans, acquired on 650 lamb carcases across 4 separate site visits.

The results of this analysis are also shown in Figure 2, where areas of intramuscular fat and surface fat have been coloured yellow and blue, respectively. Analysis of the scans takes approximately 3 seconds. This allows a person to scan the carcases as they are processed in the meat processing plant (15 per minute), prior to the carcase being stored in the chiller.

3.2 Handheld scanner

The handpiece comprises of 4 stainless-steel needles, shown in Figure 3. Each needle has two small holes near the pointed end, through which we acquire images of the meat. Inside each needle are two fibre-optic probes. The fibre-optic probe consists of an optical fibre, the thickness of a human hair (125 microns). We have developed a technique to place a highly miniaturised lens on the end of the fibre, using a similar optical design to that described by Walther et al. (Walther et al., 2022). There is also a tiny mirror inside the needle, which redirects the light out of one of the two holes drilled in the side of the stainless-steel needle. There is one hole for each fibre-optic probe.

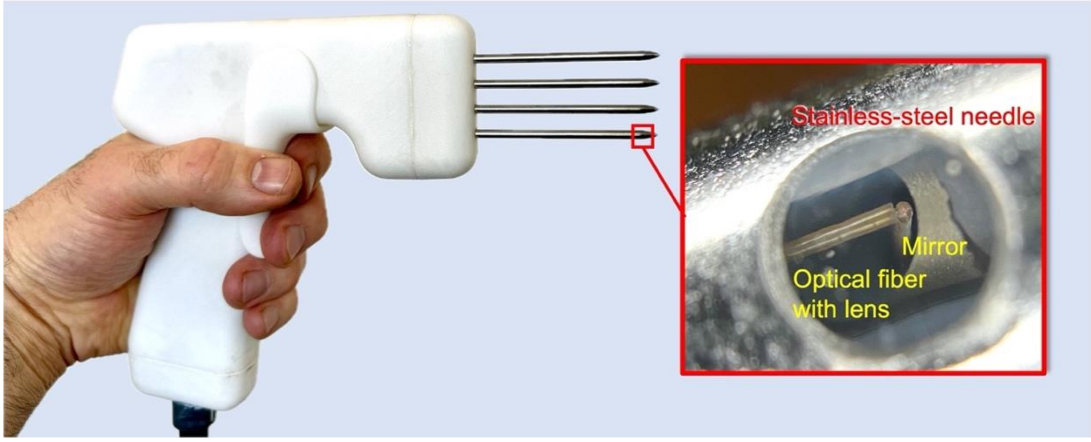

Figure 3. Handpiece with zoomed image showing the fibre-optic probe and mirror inside a needle.

3.3 Scanner console

The wall-mounted console, shown in Figure 1, comprises of a special type of optical scanner, called an optical coherence tomography scanner (Drexler and Fujimoto, 2015). These systems are commonly used in hospitals in ophthalmology (Schwartz et al., 2014) and cardiology (Bezerra et al., 2009). We have adapted this technology for use in the meat processing industry.

This optical technology shines low power, near-infrared light on the muscle. By analysing the reflections of the light, the scanner is able to generate a detailed image of the structure of the muscle and intramuscular fat. The technology is well suited to use in meat production, allowing very rapid imaging and being safe with no ionising radiation.

3.4 Field trials

Meat & Livestock Australia manage the MLA Resource Flock. This is a genetically diverse collection of sheep located across Australia. Each year, multiple batches of 100 – 250 lambs are slaughtered and characterised. Tissue samples are taken from all carcases for lab-based analysis to quantify the intramuscular fat. We have correlated the IMF% estimates calculated with our device on the hot carcase against the gold-standard, lab-based measurements of IMF%.

For the field trial detailed in this report, a portable system was used to acquire measurements at TFI, Tamworth, NSW. Measurements were taken from 250 lamb carcases. The 4 scanner needles were inserted into each carcase once to acquire 8 individual probe scans of different parts of the loin. These scans were then analysed in real-time and used to provide an estimate of the percentage of intramuscular fat for the carcase.

4 Results

The results for all 250 carcases are plotted in Figure 4. Estimates from the IMF needles were compared against gold standard measurements from chemical and NIR analysis performed by researchers from the University of New England, Armidale, NSW. Gold standard IMF values had a range from 1.6% – 8.2%.

Figure 4 shows the automated IMF needle estimates (vertical axis) plotted against gold standard values (horizontal axis). The device produced estimates with a mean absolute error of 0.68 IMF%, a root mean squared error (RMSE) of 0.87 IMF% and an R^2 of 0.48.

84% of estimates were within 1% of the gold standard IMF% measurement. 98% of the estimates were within 2% of the gold standard IMF% measurement. This satisfies the accuracy required for accreditation within the meat industry by AUS-MEAT.

The average data analysis time was 3 seconds per carcase, enabling us to analyse data at the rate that carcases are processed in a commercial meat processing plant.

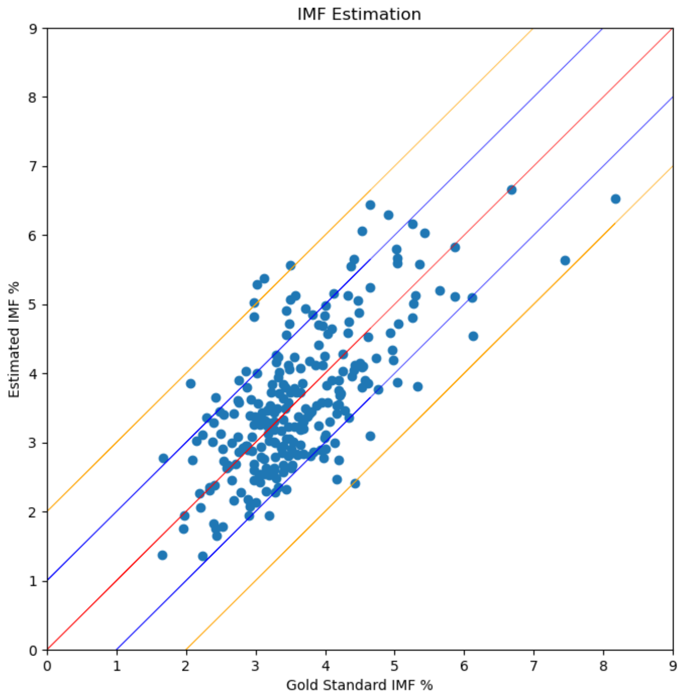

Figure 4. IMF% estimates vs gold standard values. 250 carcases. Blue lines show 1% error margin. Points within the blue lines are within 1% of the gold standard value. Orange lines show 2% error margin.

5 Preparation for AUS-MEAT accreditation

This project has undertaken significant development of a device to measure intramuscular fat in a hot lamb carcase. Prior to commercial release of this device to the Australian red meat industry, it is important for the device to receive accreditation for its estimates of IMF%. The accreditation process is managed by AUS-MEAT. Guidelines for the accreditation process outline that a trial must be undertaken using carcases that span the range of IMF% values for which the device is seeking accreditation, including at least 20 carcases for each value of IMF%. The device is required to estimate IMF% to within 1% IMF of a gold standard value 67% of the time, and to within 2% IMF of a gold standard value 95% of the time. Measurements are to be performed with at least 3 separate devices on each carcase.

Our team are currently developing the next generation of this device, which we anticipate may be appropriate to undertake an accreditation trial. In collaboration with MLA, Miniprobes has been awarded additional funding from the South Australian State Government under their Seed-Start program to undertake an accreditation trial within the next 2 years.

6 Business Plan

A confidential business plan for the commercialisation of this device has separately been submitted to MLA for review and approval.

7 Conclusion

7.1 Key findings

This project has translated a new technology to characterise meat eating quality in hot lamb carcases. The project continues on from earlier MLA-supported research undertaken by The University of Adelaide (P.PSH.1244), which provided initial experimental results indicating that this optical imaging technology has the potential to estimate intramuscular fat in a hot carcase. Within this project, we have established the following key findings:

- Optical coherence tomography is an optical imaging technology that can visualise intramuscular fat in a hot lamb carcase.
- It is feasible to incorporate the imaging optics into a small fibre-optic needle that can be used to acquire images deep within a muscle.
- Artificial intelligence (AI) algorithms can quantify the amounts of intramuscular fat with a level of accuracy that is commercially relevant.
- Quantification can be performed in real-time at speeds to match the line-speed of a commercial meat processing plant (15 carcases per minute).
- Quantification accuracy is comparable to the levels required to achieve AUS-MEAT accreditation for a device that can measure the percentage of intramuscular fat.

7.2 Benefits to industry

The development of a practical device to measure intramuscular has potential to increase the value of the Australian sheepmeat industry. In domestic markets, it would allow meat processors and retailers to segment their meat products according to meat eating quality, delivering a more consistent product to consumers and charging a premium for high quality meat. In international markets, it could provide Australian meat exporters with a commercial differentiator against product from other countries that lacks objective quality measures.

Figure 5 shows the distribution of MSA Grade 4 and 5 (high quality) meat in Loin and Topside, taken across >1400 lamb carcases from the MLA Resource Flock, described in (Pannier et al., 2014) (image adapted from (Swan et al., 2015)). For Loin, 84% of carcases were MSA Grade 4 or 5, and for Topside 8% of carcases were MSA Grade 4 or 5. If meat processors were able to identify these carcases, they would be able to charge a premium to meat consumers.

Our internal modelling of the regression between IMF% and MSA grading suggests that knowledge of IMF% will add value of approximately $7 per lamb carcase (assuming the standard deviation of IMF% within the cohort is approx. 1.5%). For mutton, we assume a much smaller value-add of $3.50 per sheep carcase.

Each year, approximately 21.4 million lambs and 6.6 million sheep are processed for meat in Australia (Meat & Livestock Australia, 2023). With a value-add of $7 per lamb carcase and $3.5 per mutton carcase, our technology could generate an additional $173mil per year for the Australian sheepmeat industry.

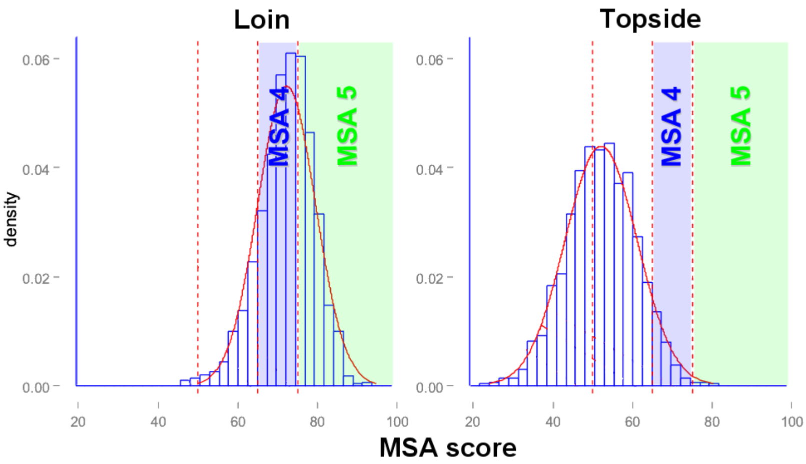

Figure 5. Observed distribution of MSA scores from >1400 animals from the MLA Resource Flock.

8 Future research and recommendations

This device to measure meat eating quality has the potential to provide significant value to the Australian red meat industry. However, to deliver this value, the technology must be successfully translated and the product commercialised to make it available to meat processors. Within this project, we have progressed through much of the technology translation to produce a prototype system that has undergone successful field trials. Future projects will be required to complete the translation and commercialisation of this device. There are several State and Federal Government schemes to finance the commercialisation of this type of Australian technology. Further support from MLA will significantly increase the likelihood of securing the necessary funding through these Government schemes.

Market adoption is also an area where MLA support will be important to ensure the success of this technology. Segments of the Australian red meat industry can be conservative in their adoption of new technologies. However, there is a growing awareness throughout the sheepmeat industry that the objective measurement of meat-eating quality offers an important opportunity for growth in the Australian industry. Schemes to support early-adopter meat processors to trial this device will increase the rate of industry adoption and help to make the development of this device commercially viable.

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