Final Report

AUSTRALIAN MEAT PROCESSOR CORPORATION

IMF of Primals

IMF of primals – End of line measurements using NMR (Stage 2)

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1.0 Executive Summary

The objective of this project was to conduct % IMF measurements of cuts or primals at the end of a meat processing line using a proof-of-concept tool, including a bespoke sensor. This project required us to identify an application, confer with processors, adapt the system for the new application, conduct a trial, and finally produce an automation concept. These steps were broken down into six milestones with a gate after surveying interest of processors.

Data was collected using a tool that was a combination of a Marbl™ single-sided NMR sensor with a Matipo spectrometer and a user interface that was developed in the project. First, we assessed primals for fit into the sensor then measured samples in the workshop to evaluate some primals that we expected would be of interest. NMR data was systematically collected on a set of primals and sub-primals, using the updated Marbl™ sensor design, with the goal to evaluate the accuracy, reproducibility, repeatability, and variation within the primal. The NMR data was used to directly predict % IMF using a model calibrated with measurements taken using a benchtop NMR instrument. We focused on the striploin data because we had independent beef marble scores for commercially available samples. On a limited number of samples we showed the measurements were repeatable, reproducible and accurate, such that graded product could be differentiated. Outcomes from these measurements were shared with processors that were surveyed.

On-site measurements were conducted in a boning room with a two conveyor, forequarter and hindquarter, layout; again we measured striploins. We measured samples from one shift of wagyu with a AusMeat marble score range of 4-9, and one half shift of 1+ AusMeat marble score resulting in >10 measured striploins in the 1+ (N=22), 4-5 (N=14), 6-7 (N=12), and 8-9 (N=11) AusMeat marble score groups. We predicted % IMF using a linear model created from 11 reference samples, where five were in the 1+ and two were in the 4-5, 6-7, and 8-9 marble score groups. There was a clear trend of increasing % IMF as the AusMeat marble score increases, as would be expected. In a violin plot, the AusMeat marble score 1+ only overlaps with a single outlier of the 4-5 wagyu group. The wagyu 4-5 and 6-7 groups do not overlap their 75% and 25% quartiles. The 6-7 and 8-9 see more overlap, however, the medians remain outside the quartiles of the other group. This overlap trend agrees with our understanding that grading becomes more difficult as marbling increases. Relative error was determined for each sample by determining the standard deviation from multiple measurements of the same striploin relative to the mean.

In the boning room, measurement time limits the application of % IMF using NMR to selected cuts so those cuts would need to be identified on the main conveyor, selected, measured and returned to the main belt. Following consideration of three generic automation concepts, it was decided that a ‘3-conveyor’ system would provide the simplest and most robust solution.

Proof-of-concept % IMF measurements of beef subprimals have been completed using an NMR sensor and this work has shown that measurements can be made of chilled meat in the boning room. Further the NMR method is accurate, provides immediate results and is non-destructive. This work contributes to the knowledge base of how objective % IMF measurements relate to subjective marble score grading. Further work is required to determine how to convert % IMF measurements within the boning room into additional value for processors.

Over the duration of this project, processors were clear in the view that tools for hot carcass grading would be extremely valuable. Knowing this from early in the project allowed us to explore it as an additional application.

2.0 Introduction

This project is the second stage of the previous AMPC project: Bovine IMF Measurement Production Prototype (McCarney and Webster, 2021). In that project we investigated what was needed to adapt an NMR sensor designed for lamb carcass % IMF measurement to beef carcass grading % IMF measurement. That project outlined feasibility and how a beef hot carcass grading system could be achieved. We proposed the current project to advance NMR-based beef grading in general while also investigating if NMR could add other value along the processing chain. In other words, this is an intermediate step between the destructive sampling system used in 2019 (Pooke and McCarney, 2019) and a full carcasses, where we develop a system that looks at primals and could be deployed in the boning room.

This project required us to propose applications, confer with processors, adapt the system for the new application, conduct a trial to test the proposed application, and finally produce an automation concept. These steps were broken down into six milestones with a gate after surveying interest of processors.

3.0 Project Objectives

The objective of this project was to conduct % IMF measurements of cuts or primals at the end of a meat processing line using a proof-of-concept tool, including a bespoke sensor. It is expected that this work will lead to either a manually-loaded stand-alone instrument or it may sit within an automated solution that includes materials (meat) handling.

4.0 Methodology

4.1 NMR data collection and processing

4.1.1 Data collection

Data was collected using a Matipo spectrometer (Resonint, Wellington NZ). During the project, the Matipo spectrometer was integrated with the sensor to measure % IMF. The spectrometer receives the NMR signal and processes it and stores the CPMG data as NumPy data files (Harris et al., 2020) on the spectrometer. The data collected was a CPMG decay and a signal to noise goal of 170 was targeted. We accepted a lower signal to noise ratio (SNR) for onsite measurements in the boning room so that more measurements on more samples could be collected. For the on-site trial a target SNR of 100 was set and measurements below 50 were excluded.

4.1.2 Data processing

This CPMG data was downloaded from the spectrometer and fit to three exponentials as described previously (Pooke and McCarney, 2019). A linear correction was applied and a % IMF prediction was made for each measurement. All analysis work was carried out in a Jupyter Notebook documented with Markdown and inline comments. The Matipo spectrometer uses Python dashboards for collecting and processing data.

4.2 Workshop development

We measured samples in our workshop to evaluate some primals that we expected would be of interest. This gave us some experience to share with processors during the survey, evaluate how they fit into the sensor, and establish an initial workflow for measurement.

4.2.1 Samples

In initial discussions with AMPC, we identified two high value primals that might be of interest to processors, which included the shortloin and rib set. We picked the D-rump as third primal with potentially high value, during our literature search. Each sample was purchased from our local butcher (Preston's Master Butcher, Wellington) to evaluate the physical fit with the current NMR sensor design. In addition, three striploins were purchased with a variety of intramuscular fat to evaluate the ability to distinguish marbling grades. Two New Zealand grass-fed Wagyu half striploins with a 3-4 and 4-5 (First Light) and a full premium striploin (Pure South) were used for a range of IMF. These were subsampled and reference were made in the Halbach geometry sensor, Oscar 2.0.

4.2.2 Collecting NMR data

NMR data was systematically collected on a set of primals and sub-primal, using the updated Marbl™ sensor design, with the goal to evaluate the accuracy, reproducibility, repeatability, and variation within the primal. The NMR data was used to directly predict % IMF. We focused on the striploin data because we had independent beef marble scores for two of the three and expected the third to be a lower marble score. We also felt that the striploin has the best value proposition of all the subprimals.

4.3 Processor Surveys

A briefing note was written to share with AMPC and potential processors. This note provided information about the technology and a concept for a stand-alone instrument. We used this to discuss our ideas with both AMPC and processors. An introductory discussion with Greg Williams and Stuart Shaw, AMPC, informed us on who we should try to engage with based on products and process. It also prepared us for challenges that would be repeat concerns of processors. AMPC identified a number of companies, contacted a number of processors, and set up meetings. At least 9 processors were approached. Of these we engaged with four. Others were contacted but were either not interested, too busy or a meeting was never confirmed. The surveys were conducted as on-line Q & A meetings.

From the surveys, inMR was keen to:

1. get an industry perspective on the concept of the device
2. build the value position, specifically which cuts would it be best to measure
3. understand where it would be used in the boning room and the necessary speed of measurement (based on throughput).
4. Find companies that would be interested in participating in a trial. Our initial plan was to trial at just one site.

4.4 Onsite Processor Trial

4.4.1 Boning room design

The boning room had two conveyers that divide the process into forequarter and hindquarter lines where the associated primals follow their respective path. That means the high value striploins and cube rolls were on different conveyors. To measure both would require separate NMR instruments or moving the equipment or product. There was no reasonable solution to movement between sides of the boning room. For this reason we focused on striploins. The Marbl^{TM} Boning Room instrument was setup at the hindquarter conveyor. The striploin is removed from the shortloin in one of the last steps of the hindquarter boning sequence. This located the NMR instrument towards the end of the boning room before tagging and bagging. The processor does not portion or retail pack, so we were essentially measuring their final product.

This is just one boning room design and what we found here does not apply universally. It suggests that site requirements could stifle flexibility of NMR applications. Even slightly different applications are likely to require separate NMR instruments rather than rolling from one space to another as required. It also means that automation solutions will likely be site specific even within one processing facility.

4.4.2 Samples

We managed to get one shift of wagyu with a AusMeat range of 4-9, and one half shift of 1+ AusMeat marble score resulting in >10 measured striploins in the 1+ (N=22), 4-5 (N=14), 6-7 (N=12), and 8-9 (N=11) AusMeat marble score groups. This left a small gap between, 2-4, however, we recognize that this could be an important band of product. Due to a lack of time we focused on striploins, however, we measured two cube rolls and five skirt samples.

4.4.3 IMF reference samples

The product owners generously donated 11 slices of striploin for us to use as IMF reference samples. These included two from each wagyu mabling band 4-5, 6-7, 8-9, and five from 1.0-1.6 AusMeat marble scores. The samples were 2 cm slices off the grading cut surface of the striploin. These samples were transferred to Dr. Peter McGilchrist for gold standard % IMF analysis at University of New England.

4.4.4 NMR Measurements

In the case of wagyu, striploins were pulled from the belt after being tagged with a marble score at the conveyor belt. These scores were in grades of two units. For the beef 1+ batch the range was 1.0 - 1.6. NMR data was collected using the user interface developed in Milestone 4. Individual striploins were measured 2-6 times depending on consistency between measurements. The measurement time was about 20 seconds and the sample was repositioned between replicate measurements of a sample.

5.0 Project Outcomes

5.1 User Interface

As part of this project we designed a user interface to make the system easier to use for collecting data on primals and batches of primals. The user interface was modelled after other data collection software that the authors have developed for similar high throughput applications. It has standard components that allow for sample identification, data collection, % IMF prediction and output, a log of data collected in a batch, and statistics of that batch. At this time, the interface has been kept simple because we are still looking for further feedback before significant investment is put into developing a stable version. The state of the interface, as of writing this report, is shown in Figure 1.

The IMF parameters are displayed after the acquisition has completed. These results are added to the Data Log below the current results. The Statistics table provides statistics on the current Batch for each of the output parameters, including count, mean, standard deviation, minimum, maximum, and quartiles.

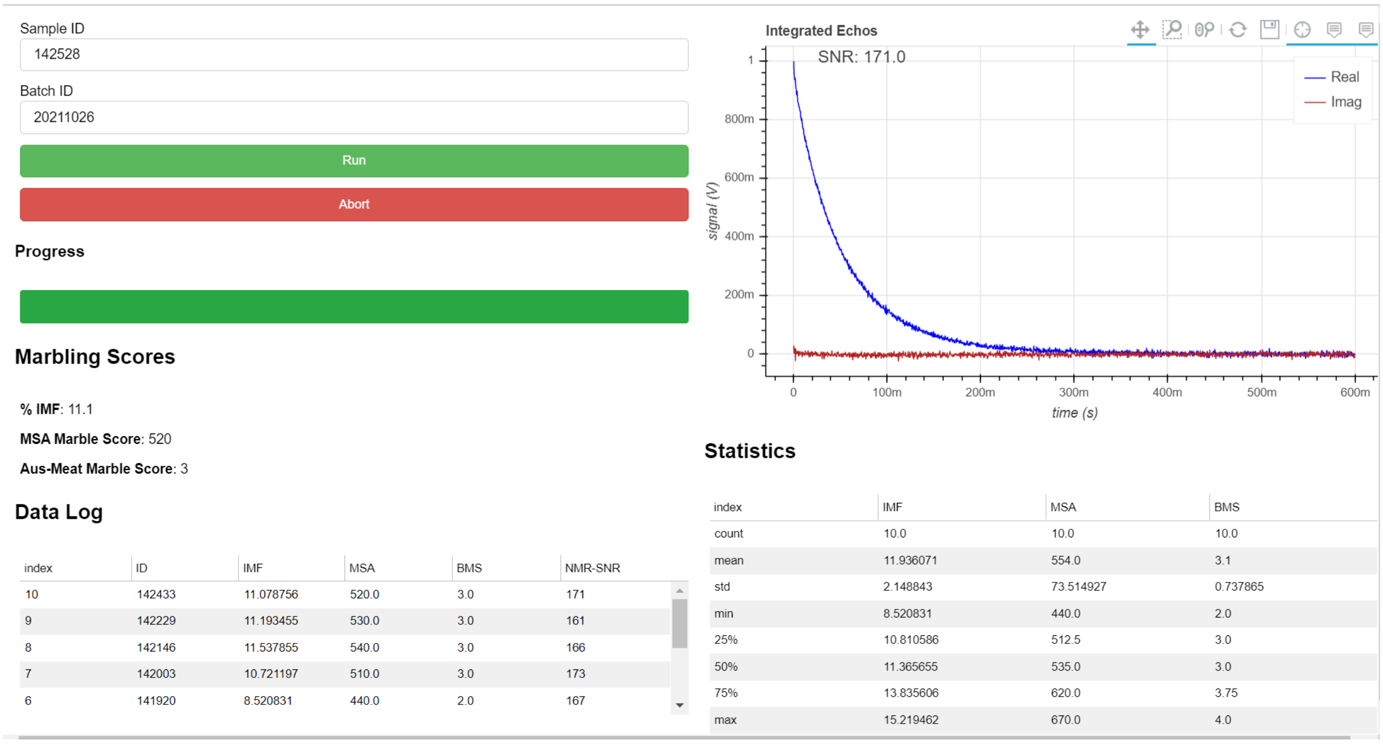

Figure 1. User interface developed for the end of line boning room % IMF prediction system.

The raw NMR data is saved by sample ID and can be reprocessed later. The data log is saved as a text file in the batch folder. As the industry is more familiar with MSA Marbling Score and AusMeat Marbling Score, the % IMF measurements can be converted and presented accordingly. At the moment this is done with a linear relationship between % IMF and marble score based on data we have collected so far. This is a small dataset with more weight on the higher marble scores. The low marble score prediction is not yet reliable. This conversion is currently under development (personal communication, ALMTech).

5.2 Fit of primals

The primals that we evaluated fit into the sensor differently, with the shortloin being a poor fit, striploins and rump a reasonable fit, and OP rib roast and cube roll a good fit. The skirt was too thin on its own for the current sensor configuration locating most of the meat in the insensitive region. The large variation in fit suggests different designs specific to the use would improve the user experience and possibly increase the measurement sensitivity. The highest value sub-primals (striploin, tenderloin, and cube roll) all fit well on the sensor, however, thickness and location of non-IMF fat needs to be considered for specific measurements.

5.3 Striploin comparison

Striploins are a graded high value sub-primal giving us the opportunity to put % IMF in context with marble score. Wagyu striploins are often marketed on their marble scores. The NMR measurements of the three striploins were compared over multiple days. Figure 2 shows the NMR values of Preston's on two different days and First Light marble score 3-4 (FL 3-4) and First Light marble score 5-6 (FL 5-6) collected on four different days.

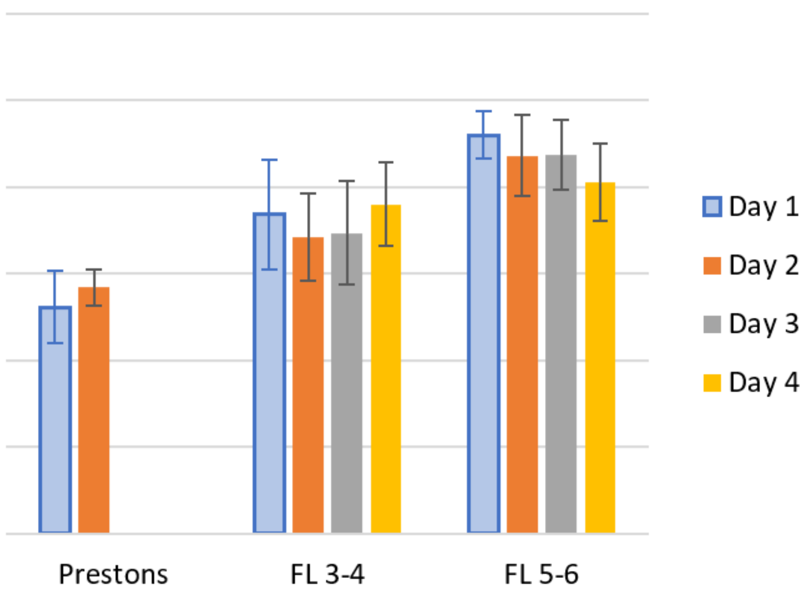

Figure 2. Comparison of the mean NMR fit values collected over two to four different days. At least four measurements were averaged for each day. Prestons was from a local butcher and FL 3-4 and 5-6 were purchased online from First Light.

The results show the following:

- The data collected on subsequent days are not statistically different
- The NMR can differentiate the three marble grades

There is still significant scatter in the data that can be explained when sorting the data by the location along the length of the striploin. The mean NMR fit parameter and statistics of the measurements made at each end are compared in Figure 3. The data suggests that one end of the strip loin FL 3-4 could be a different grade than the other.

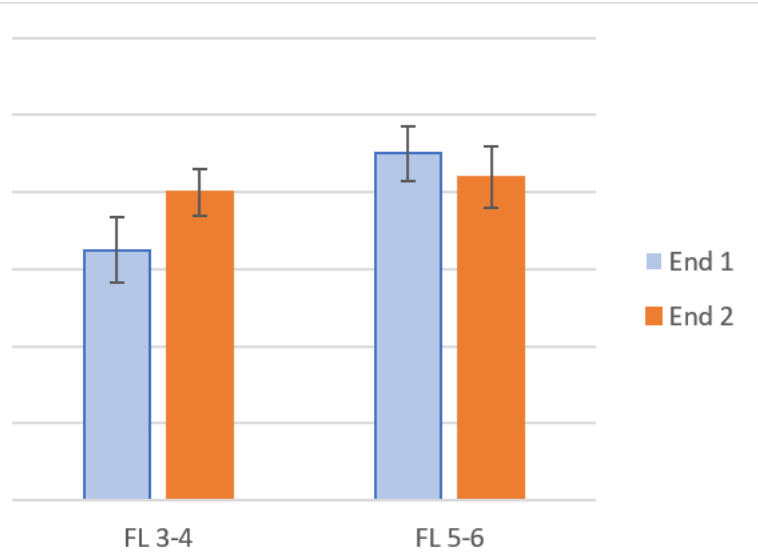

Figure 3. The two ends of the FL 3-4 strip loins are predicted to have different marbling and % IMF scores, while the FL 5-6 ends are predicted to be within error of each other.

5.4 Statistical analysis of workshop results

5.4.1 Accuracy

We calibrated our Marbl™ NMR results against measurements on a Halbach geometry NMR system, Oscar, to correct the % IMF. We also converted the % IMF to MSA marbling score from FTIR IMF data collected on the 20 graded short loins measured in May 2021 (McCarney and Webster, 2021). This can then be used to bin the meat into a marble score range and finally compare our prediction to the manufacturer's grade. This process is shown in Table 1. The different grades of meat fall into different marble score values. The Preston's striploin is expected to be less than 3, but the noticeable intramuscular fat suggested that a marble score of 2 is reasonable. The independent grading range specified by First Light match our prediction for the marble score 3-4 striploin, but we under predict the marble score of the marble score 5-6 strip loin. The error in our prediction does not exclude the possibility of being a marble score 5 even though the mean falls in the marble score 4 range. We also know that the grading is performed at a single site and then applied to the whole carcases, so the striploin half we purchased might be posterior half far from the grading site.

Table 1: The predicted % IMF, MSA marbling score, and marble score marbling scores for the three striploins measured in this project.

	Estimated % IMF	MSA Mable Score	Marble score Equivalent
Prestons	7.9	420	2
First Light 3-4	10.9	520	3
First Light 5-6	15.1	660	4*

* This is within error of marble score 5.

5.4.2 Reproducibility

We investigated reproducibility by measuring at different locations and different sides of the sub-primals. Previous studies have shown significant heterogeneity across a striploin (McCarney and Webster, 2021; Stewart, S.M. et al., 2020). It is therefore difficult to evaluate the reproducibility using different measurement locations. Figure 3 shows that the two ends of the First Light grade 3-4 sample have significantly different IMF contents. The grade 5-6 is more consistent throughout the sub-primal.

One key takeaway from this work is the robustness of NMR. The Oscar model was created over two years ago on a very different NMR system and we can still predict % IMF on our current system. This is not an extensive study of reproducibility; however, these results are very promising.

5.4.3 Repeatability

Repeatability was investigated by looking at measurements across several days. This is best captured by the First Light samples measured over four days (Figure. 2). This shows the variability of approximately 10% (relative) was constant over the course of the four days. This equates to about +/- 1.5% IMF or +/-60 MSA marbling units at the largest variances. This variability is more likely associated with sample heterogeneity observed by sample placement than day to day fluctuations in the NMR measurements.

5.5 Survey Results

5.5.1 Cuts worth measuring

The interviews provided consensus on a set of cuts where potential value could be added by measuring % IMF. These were the shortloin and ribset primals and the related striploin, tenderloin and cube roll. In addition, it was suggested that grading skirt might also add value because it was separated from the carcass before a grade was assigned.

An opportunity noted was the potential to measure IMF along sub-primals to create differentiation/value. An extension of this was the suggestion of graded cutting of steak. This is something we will consider but it highlights that for meat processors producing retail cuts, % IMF measurements could open some new opportunities. Notably, our work showed that in instances there are measureable differences in % IMF within sub-primals, such that creating product differentiation is possible.

5.5.2 Where in the plant to make measurements

It was clear from the interviews that measuring % IMF at the end of the line was too late. The measurement needs to be made at the boning tables prior to where meat is labelled, put into packages and then into cartons.

5.6 Trial results

Reference samples

We collected reference samples for gold standard FTIR % IMF measurements by the University of New England (UNE). The IMF were compared to the NMR resulting in a correlation (R^2) of 0.97 (Figure 4). The RMSEP of the values predicted from the linear fit is 1.34 % IMF. This relationship between NMR and the FTIR gold standard is almost as good as the FTIR and chemical IMF. The Marbl™ boning room system has the added benefits of being fast, non-destructive and onsite.

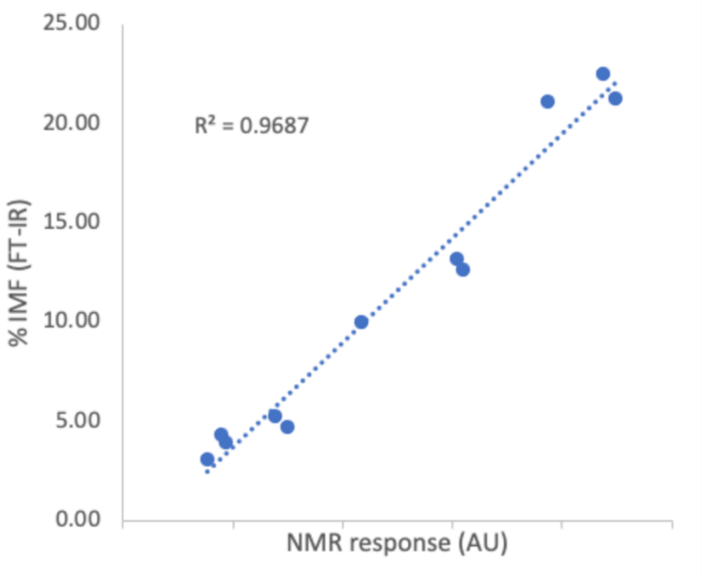

Figure 4. Correlation of NMR response with % IMF measured by the gold standard method FTIR of freeze dried samples.

5.6.1 IMF Prediction

We predicted IMF of all the samples using a linear model created from the reference data. A violin plot shows the occurrence density of the % IMF prediction within each marbling group in Figure 5. There is a clear trend of increasing % IMF as the marble score increases, as would be expected. The dashed lines represent the median value and the dotted lines represent the 25% and 75% quartiles. The plots are cut off at the maximum and minimum predictions. The AusMeat marble score 1+ only overlaps with a single outlier of the 4-5 wagyu group. The wagyu 4-5 and 6-7 groups do not overlap their 75% and 25% quartiles. The 6-7 and 8-9 see more overlap, however, the medians remain outside the quartiles of the other group. This overlap trend agrees with our understanding that grading becomes more difficult as marbling increases. The exact % IMF will be determined with the help of the 11 reference samples sent to UNE for FT-IR measurements when the data is available.

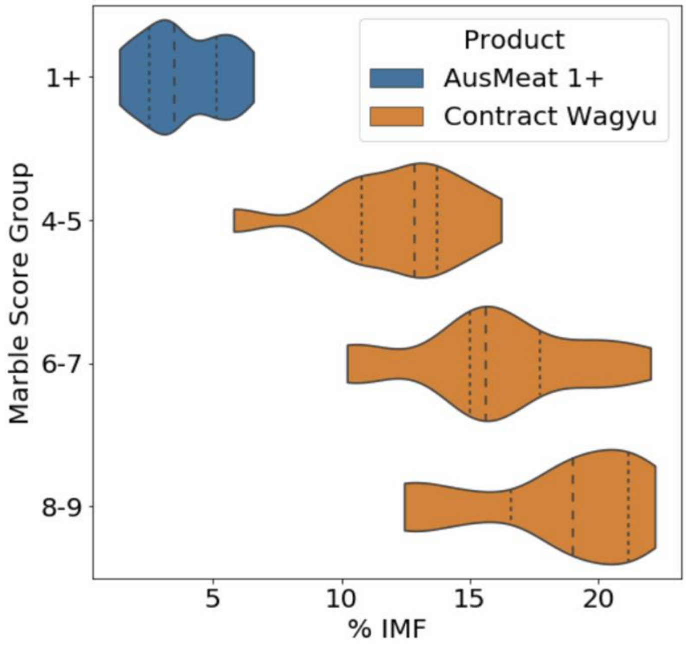

Figure 5. Violin plot showing occurrence density of % IMF predicted by the NMR measurements on the x-axis within each marbling group along the y-axis.

5.6.2 Heterogeneity, variance, and measurement error

Measurement variability is critical to confidently predicting properties of the sample. Relative error was determined for each sample by determining the standard deviation from multiple measurements of the same striploin relative to the mean. The SNR is the average signal to noise of those samples. Figure 6 shows that susceptability to large error decreases as signal to noise increases. The plot is colour-coded by product where purple is AusMeat marble score 1+ and orange is wagyu. The remnant error towards high SNR is most likely related to the sample heterogenetity.

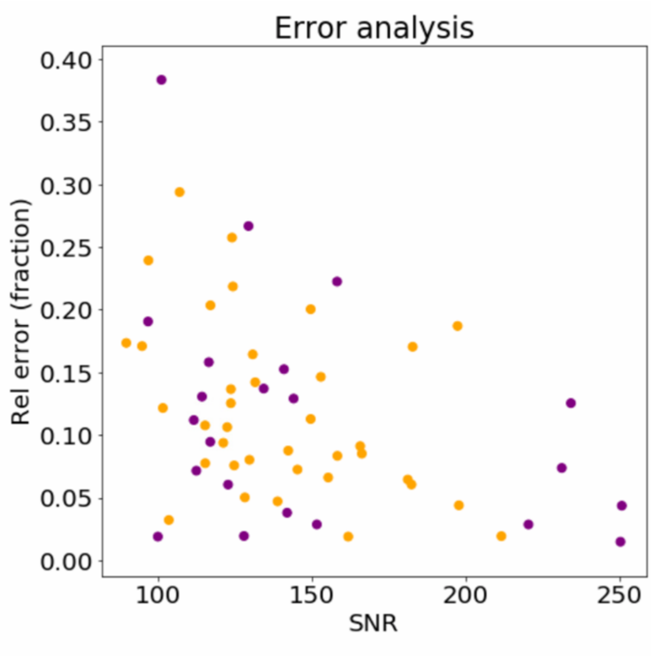

Figure 6. The relative error of multiple measurements of a striploin as a function of the average signal to noise for that sample. Orange points represent wagyu and purple points represent AusMeat marble score 1+ product.

5.7 Automation concepts

In the boning room, measurement time limits the application of % IMF using NMR to selected cuts. Therefore automated measurements would require the following generic steps:

- identify the sample
- locate the sample
- make the measurement
- return the sample to the main conveyor.

Following consideration of three generic automation concepts, it was decided that a '3-conveyor' system would provide the simplest and robust solution. Specific design input, e.g. footprint, room layout etc, would be needed to warrant progressing automation.

6.0 Conclusions / Recommendations

In-line with the objective of this project, proof-of-concept % IMF measurements of beef subprimals have been completed using an NMR sensor. The Marbl™ sensor is designed for single-sided measurements and with this work it was shown that measurements can be made of chilled meat in the boning room. Application of % IMF measurements using this tool in the boning room is best used for selected cuts.

This work contributes to building the knowledge base of how objective % IMF measurements relate to subjective marble score grading. At the time of writing this report ALMTech was developing a conversion algorithm from % IMF to marble score. We plan to incorporate this when it's available. More detailed work is required to convert % IMF or marble score measurements in the boning room into additional value for processors.

Over the duration of this project, processors were clear in the view that tools for hot carcass grading would be extremely valuable. Knowing this from early in the project allowed us to explore it as an additional application.

7.0 Bibliography

Harris, C.R., Millman, K.J., van der Walt, S.J., Gommers, R., Virtanen, P., Cournapeau, D., Wieser, E., Taylor, J., Berg, S., Smith, N.J., Kern, R., Picus, M., Hoyer, S., van Kerkwijk, M.H., Brett, M., Haldane, A., del Río, J.F., Wiebe, M., Peterson, P., Gérard-Marchant, P., Sheppard, K., Reddy, T., Weckesser, W., Abbasi, H., Gohlke, C., Oliphant, T.E., 2020. Array programming with NumPy. Nature 585, 357–362. https://doi.org/10.1038/s41586-020-2649-2

McCarney, E., Webster, B., 2021. Bovine IMF: Stage 1 for a Non-destructive prototype (No. 2021–1128). Australian Meat Processor Corporation Ltd.

Pooke, D., McCarney, E., 2019. NMR Measurement of Intra-Muscular Fat (No. V.RDP.2110). Meat & Livestock Australia Limited.

Stewart, S.M., Gardner, G.E., Williams, A., Pethick, D.W., McGilchrist, P., Kuchida, K., 2020. Association between visual marbling score and chemical intramuscular fat with camera marbling percentage in Australian beef carcasses. Meat Science 108369. https://doi.org/10.1016/j.meatsci.2020.108369

Stewart, S.M., Pethick, D.W., Gardner, GE., 2020. The distribution of chemical Intramuscular fat percentage within M. Longissimus Dorsi in Australian beef carcasses (No. KPI 7.1.10), Advanced measurement technologies for globally competitive Australian meat. Advanced Livestock Measurement Technologies.