final report

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Develop on-line NMR measurement technologies for beef and sheep meat

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Executive summary

This research was conducted in three parts:

1. Consult at least two key processors from Australia & NZ on generic on-line measurement capabilities and what potential applications they may have. Consult key technical groups on latest developments in LF-NMR technologies. Prepare a cost benefit analysis with defined assumptions. Interim report on preliminary review process and feasibility analysis to MLA & MWNZ. Low-field equipment identified in consultation with Magritek in readiness for validation trials.

2. Conduct validation trials with low-field NMR equipment to measure specified eating quality traits. Report on: 1) trials to verify the modifications to the NMR-MOLE have eliminated the temperature instability of the magnetic field. 2) preliminary trials of the modified NMR-MOLE or alternative low-field NMR technology to measure pH, shear force and water holding capacity.

3. Carry out comprehensive trials alongside Sheep CRC information nucleus progeny slaughters. Develop NMR prediction models for all meat quality attributes measured in the trials. Final report to MLA & M&WNZ. Finalise proposal in consultation with commercialiser, MLA & M&WNZ for ongoing technical & marketing work on pre-production NMR prototype & submit to MDC for ongoing funding.

The cost benefit analysis study (Part 1) of three Australian and two New Zealand lamb processors. Processors were consulted about the application and feasibility of using NMR technologies on-line in a meat processing facility, as well as the likely benefits that the on-line technology could provide.

The industry consultation identified six potential benefits that NMR could provide for the Australian and NZ lamb processing industry. Five of these were expected to provide significant economic benefits and were therefore included in a cost/benefit analysis. The sixth potential benefit was the ability to use NMR as a lab-based tool for analysis or research purposes; this was not included in the cost/benefit analysis because it is unlikely to result in significant net economic benefits for the industry. The cost/benefit analysis was carried out using published industry data and by making several assumptions about the costs, benefits and uptake of the NMR technology across the Australian and NZ lamb processing industry. At maximum uptake levels the individual benefits were estimated to return the following to the NZ and Australian lamb processing industries:

a) Classification tool – NZ$ 18.0 million p.a. from year 10

b) Upgrading tool – NZ$ 10.8 million p.a. from year 10

c) Filtering tool – NZ$ 9.7 million p.a. from year 10

d) Feedback tool – NZ$ 16.0 million p.a. from year 13

e) Marketing tool – NZ$ 16.7 million p.a. from year 10

The most significant assumption in the cost/benefit analysis was that the NMR technology could actually be used to achieve all the benefits identified by the industry consultation. If this was the case, the NMR project was estimated to have a net present value (NPV) of NZ$148 million (or A$129 million at exchange rate of 0.87) and an internal rate of return (IRR) of 98% over twenty years. However, we believe it is unlikely that NMR could provide all of these benefits. Therefore, the cost/benefit analysis was recalculated assuming that only one of the identified benefits (benefit a) could be provided by NMR. This reduced the NPV to NZ$ 34 million and the IRR to 60%. This recalculation indicated that NMR is still an excellent investment if only this one benefit can be successfully achieved.

Overall, If only one of the identified benefits could be provided by NMR, the NPV is estimated to be NZ$ 34 million and the IRR to 60%. The analysis indicated that NMR is still an excellent investment if only one benefit can be successfully achieved.

Milestones 2 & 3 (Parts 2 & 3 of the study) has been carried out using the available Magritek Halbach LF-NMR system. Although this system is not open-topped (i.e. a sample must be removed from the meat in order to take a measurement) it provides the ability to prove the concept of LF-NMR measuring meat quality attributes. The Halbach may also have its own application within the meat industry as a rapid lab-based measurement system.

Two trials were conducted in collaboration with the Australian Sheep CRC Information Nucleus (IN) flocks from Armidale, NSW. The measurements obtained from the IN flocks provided the ideal opportunity across a large number of samples (n=148) for the LF-NMR to be tested and validated for a range of genotypes and with variation in meat quality under in-plant conditions.

In the experiment additional instrumental variations were experienced that had not been observed before. The probe output amplitude changed significantly during the trials and should be included as variable in future studies. This instability was likely to have had a significant effect on the development of correlations to meat quality attributes.

The observed correlations (R^2) between pH, drip and shear force with NMR relaxation measurements were low, but significant, varying between 0.30 and 0.35. These were not as strong as previous studies, presumably due to the instability of the NMR Halbach instrument.

Submission to MDC (MLA Donor Company) for ongoing funding through their partnership programme was previously planned in the milestone, dependent on FRST funding being secured; however, the FRST concept sketch for NMR was not successful so no submission to MDC can be made. A proposal for ongoing work has been submitted to MLA and MIRINZ Inc.

Contents

Background

Early work shows there is a strong possibility of using nuclear magnetic resonance to measure meat quality attributes on-line. However, it is the development of an appropriate device that can be adapted to commercial situations that is the enabling technology.

Bench-top Low-Field NMR units have been used to measure certain aspects of meat quality. LF-NMR has been accepted in Sweden as a standard method for total fat analysis in meat and meat products since 1985.

Nuclear magnetic resonance (NMR) is a physical phenomenon based upon the magnetic property of an atom's nucleus. All nuclei that contain odd numbers of nucleons and some that contain even numbers of nucleons have an intrinsic magnetic moment. The most often-used nuclei are hydrogen-1 and carbon-13, although certain isotopes of many other elements nuclei can also be observed. NMR studies a magnetic nucleus, like that of a hydrogen atom (protium being the most receptive isotope at natural abundance) by aligning it with a very powerful external magnetic field and perturbing this alignment using an electromagnetic field. The response to the field by perturbing is what is exploited in nuclear magnetic resonance spectroscopy (high-field NMR) and magnetic resonance imaging (MRI) as well as nuclear magnetic relaxometry (low-field NMR).

LF-NMR has been used for determining water compartments and cooking. A good correlation between LF-NMR and water holding capacity has been found. Several other meat properties were studied as well as pre and post rigor changes.

There is evidence in the literature that low field nuclear magnetic resonance (LF-NMR) can measure fat levels in meat and changes in water compartments in lean tissue associated with rigor, water binding and cooking. This indicates potential to measure key meat quality attributes using LF-NMR. However, existing LF-NMR bench top units are impracticable for on-line use in meat plants.

The development of new LF-NMR devices by Magritek that allow meat to be placed on top of the device may enable on-line measurement of meat properties. Current work, carried out alongside Magritek, is focusing on examination of the Magritek LF-NMR devices to test whether key meat quality attributes show measurable responses.

Assuming that the current LF-NMR study indicates that Magritek devices can measure key quality attributes, further work will be required to develop accurate measures for specific attributes. This work is outlined in this proposal.

LF-NMR has the potential to manage quality during processing and predict product performance in the market as well as providing robust data which can be fed back to farmers and used in decision support.

Project Outline

The following are the milestones:

Milestone	Milestone Description
1	Consult at least two key processors from Australia & NZ on generic on-line measurement capabilities and what potential applications they may have. Consult key technical groups on latest developments in LF-NMR technologies. Prepare a cost benefit analysis with defined assumptions. Interim report on preliminary review process and feasibility analysis to MLA & MWNZ. Low-field equipment identified in consultation with Magritek in readiness for validation trials.
2	Conduct validation trials with low-field NMR equipment to measure specified eating quality traits. Report on: i) trials to verify the modifications to the NMR MOLE have eliminated the temperature instability of the magnetic field and ii) preliminary trials of the modified NMR-MOLE or alternative low-field NMR technology to measure pH, shear force and water holding capacity.
3	Carry out comprehensive trials alongside Sheep CRC information nucleus progeny slaughters. Develop NMR prediction models for all meat quality attributes measured in the trials. Final report to MLA & MWNZ. Finalise proposal in consultation with commercialiser, MLA & MWNZ for ongoing technical & marketing work on pre-production NMR prototype & submit to MDC for ongoing funding.

Project Objectives

The overall purpose of this research is to evaluate Low Field Nuclear Magnetic Resonance technology for on-line measurement of meat quality attributes.

The objectives of the project were :

* Cost benefit analysis on NMR technology
* Report on the ability of the NMR-MOLE to predict meat quality attributes

Experimental work

Part 1 - Consult at 5-6 processors from Australia & NZ on generic on-line measurement capabilities and what potential applications they may have. Consult key technical groups on latest developments in LF-NMR technologies. Prepare a cost benefit analysis with defined assumptions. Outcomes to be reviewed by project review committee. Critical decision point

Part 2 - Conduct validation trials with low-field NMR equipment to measure specified eating quality traits. Report on: 1) trials to verify the modifications to the NMR-MOLE have eliminated the temperature instability of the magnetic field. 2) preliminary trials of the modified NMR-MOLE or alternative low-field NMR technology to measure pH, shear force and water holding capacity using Sheep CRC information Nucleus sheep.

Part 3 - Carry out comprehensive trials alongside Sheep CRC information nucleus progeny slaughters. Develop NMR prediction models for meat quality attributes measured in the trials. Final report to MLA & M&WNZ. Finalise proposal in consultation with commercialiser, MLA & M&WNZ for ongoing technical & marketing work on pre-production NMR prototype & submit to MDC for ongoing funding.

Results & Discussion

Refer to the supporting documents for detailed papers for each of the milestones (see Appendix):

Appendix A – Industry consultation and cost/benefit analysis of Low Field Nuclear Magnetic Resonance (LF-NMR) for on-line measurement of meat quality attributes (Milestone 1)

Appendix B – Development and evaluation of NMR prediction models for meat quality attributes (Milestones 2 & 3)

Conclusion

Objective 1 has been met and reported on in CR 1237. The industry consultation identified six potential benefits that NMR could provide for the Australian and NZ lamb processing industry. Five of these were expected to provide significant economic benefits and were therefore included in the cost/benefit analysis. If the NMR technology could achieve all the benefits identified by the industry consultation, the net present value (NPV) was estimated at NZ$148 million (or A$129 million at exchange rate of 0.87) and an internal rate of return (IRR) of 98% over twenty years. If only one of the identified benefits could be provided by NMR, this reduced the NPV to NZ$ 34 million and the IRR to 60%. The analysis indicated that NMR is still an excellent investment if only one benefit can be successfully achieved.

Objective 2.1 relies on the availability of the improved Magritek NMR-MOLE. Unfortunately the modified MOLE was not available for use, so the trials to verify the temperature stability of the instrument have not yet been carried out. This work will be carried out and reported on once the MOLE is available*. We estimate that this will be available for use by December 2008.

Objectives 2.2 and 3 have been carried out using the available Magritek Halbach system. Although this system is not open-topped (i.e. a sample must be removed from the meat in order to take a measurement) it provides the ability to prove the concept of NMR measuring meat quality attributes. The Halbach may also have its own application within the meat industry as a rapid lab-based measurement system. Two trials alongside the Sheep CRC are now completed. The base test results will be completed by mid-August and so we are on track to carry out the data analysis and report the final results in September 2008.

Since the improved MOLE was unable to be included in Objectives 2.2 and 3, we have reduced the number of Sheep CRC trials using the Halbach system in order to retain some funds, which will allow preliminary trials to be carried out with the improved MOLE (to measure pH, shear force and water holding capacity) when it becomes available*.

*the availability of the improved MOLE is dependent on Magritek.

Recommendations / Commercial

Once the modified NMR-MOLE has been shown to be temperature-stable. A standard material will be chosen to test the stability of the MOLE in future trials. LF-NMR parameters that define the stability of the instruments and best conditions for use will also be defined. Protocols for its use will be developed.

Two trials will be carried out in alignment with the Australian sheep CRC information nucleus progeny slaughters. These trials will be based on protocols and parameters developed above and will allow the development of accurate prediction equations for meat quality attributes using the improved MOLE. The accuracy of the predictions will be defined based on the accuracy of reference measurements.

Milestone 2.1 relies on the availability of the improved Magritek NMR-MOLE. Unfortunately the modified MOLE was not available for use, so the trials to verify the temperature stability of the instrument have not yet been carried out. This work will be carried out and reported on once the MOLE is available. We estimate that objective 2.1 will be completed by February 2009.

The outputs at 30 September 2009 will provide indications of the ability of the improved MOLE to predict commercially relevant meat quality traits in a meat plant environment.

Submission to MDC (MLA Donor Company) for ongoing funding through their partnership programme was previously planned in the milestone, dependent on FRST funding being secured; however, the FRST concept sketch for NMR was not successful so no submission to MDC can be made. A proposal for ongoing work has been submitted to MLA and MIRINZ Inc.

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Two trials for Milestone 2.2 have recently been conducted using the Halbach in collaboration with the Australian Sheep CRC Information Nucleus (IN) flocks from Armidale, NSW. The extensive list of measurements obtained from the IN flocks provides the ideal opportunity across a large number of samples (n=160) for online technologies to be tested and validated for a range of genotypes and with variation in meat quality under in-plant conditions.

The overall outcomes of the project were:

1) New Technology: - LF-NMR for measuring meat quality attributes.

2) Commercialisation/Dissemination Strategy: Discuss project with potential commercialisers to attract investment. Work with processors to develop NMR as an on-line measurement technology.

Acknowledgements

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication. MLA partnered with Meat and Wool New Zealand and wishes to acknowledge their contribution to the project. NMR studies were shared between MWNZ and MLA. The intellectual property is shared between MLA and M&WNZ, on the condition that MIRINZ Inc will be acknowledged in any media release or public statement concerning the results of the MLA / M&WNZ collaborative research program.

Appendix A

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Industry consultation and cost/benefit analysis of Low Field Nuclear Magnetic Resonance (LF-NMR) for on-line measurement of meat quality attributes

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Summary

Milestone and achievement criteria
Consult at 5-6 processors from Australia & NZ on generic on-line measurement capabilities and what potential applications they may have. Consult key technical groups on latest developments in LF-NMR technologies. Prepare a cost benefit analysis with defined assumptions. Outcomes to be reviewed by project review committee. Critical decision point.

Three Australian and two New Zealand lamb processors were consulted about the application and feasibility of using NMR technologies on-line in a meat processing facility, as well as the likely benefits that the on-line technology could provide.

The industry consultation identified six potential benefits that NMR could provide for the Australian and NZ lamb processing industry. Five of these were expected to provide significant economic benefits and were therefore included in a cost/benefit analysis. The sixth potential benefit was the ability to use NMR as a lab-based tool for analysis or research purposes; this was not included in the cost/benefit analysis because it is unlikely to result in significant net economic benefits for the industry. The cost/benefit analysis was carried out using published industry data and by making several assumptions about the costs, benefits and uptake of the NMR technology across the Australian and NZ lamb processing industry. At maximum uptake levels the individual benefits were estimated to return the following to the NZ and Australian lamb processing industries:

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to 60%. This recalculation indicated that NMR is still an excellent investment if only this one benefit can be successfully achieved.

Contents

1. Approach for Industry Consultation

Three Australian and two New Zealand lamb processors were consulted about the application and feasibility of using NMR technologies on-line in a meat processing facility. A 2-page handout was sent to them to explain NMR and the project aims (given in Appendix 1). Following this the processors were interviewed over the phone or face-to-face to collect their thoughts.

2. Summary of Responses from Australian and New Zealand Lamb Processors

Australian Meat Processor 1 (AMP1)

Processor 1 is a predominantly export abattoir with 95% product going frozen. This plant kills around 5000 sheep per day - both lambs and a large mutton turnover.

They are currently ‘industry leaders’ in terms of adoption of new technologies. They have installed a number of prototype electrical input equipments and as a result we believe that they may be a suitable candidate to try any prototype NMR based systems in the future.

Currently this processor grades carcasses immediately before entering chiller on size. The following points were raised:

- Would want a system that can grade into chiller
- Want a robust and simple system
- Would want system to be able to pick out poorer quality bottom end product.
- Would use system in house only to grade mutton into markets depending on cooking style - in the middle east they tend to ‘boil’ meat for a very long time - so poorer quality would be suitable for these markets cuts whereas the better quality cuts would suit the Asian markets as they cook for shorter (grilling style cooking).
- Would want to conduct a significant cost benefit analysis and feasibility study.
- Would also use this technology to grade higher eating quality merino product into cross bred chilled market. Currently it goes frozen.
- Would be useful if this system could grade eye muscle area.
- They believe this system may give them the market edge - hypothetically could work well as a grading system
- Not so worried about getting a higher price for the NMR assessed premium product.
- Benefits of potentially decreasing the potential of getting a bad eating quality experience would be high.

- They would not use this system to downgrade product.
- Concerns about whether this system would be able to cope with chain speed restrictions.
- Would this technology be easy to implement?
- Feedback system: would not be used to give feedback to farmers. Would primarily be used as in-house grading system
- Might only be interested in it for loins
- They are about to set up their own feedlot. Potential to link into feedlot system
- Once graded - carcasses would be auto sprayed with a number/grading system.
- Would need to come to their plant fully automated and installed.

Australian Meat Processors 2 (AMP2)

This plant is 100% domestic. 20% of product goes to high end consumers such as David Jones, the remainder to ‘budget’ stores. The budget stores just want cheap meat.

They perceive the carcass presentation to be most important in terms of current grading system as they make a lot of sales of whole carcasses to butchers shops.

The following points were raised:

- They would want something that is both a visual and quality approach.
- Would want this system to grade straight into the chiller
- They would demand a premium for the product assessed ‘high quality’.
- The discussed a potential area of research involving the role of NMR to assist in lamb age classification. Potential area of research - Murdoch University Research work has shown the eye lens weight can determine the age of a sheep within a week of age. Does the NMR have the potential to be used to age animals??
- The NMR system should have no on-line costs after installation if possible.
- They believed that the best way to get this system implemented is to push the big supermarkets in the same way that electrical stimulation was pushed by Woolworths in Australia. However, they predicts that the supermarkets won’t financially assist the lamb processors to install this technology just expect it to be done or will go to another processor - could this pose problems?
- Anything going to EU market may require NMR measurement. This market pays more and could afford to pay more for quality.

Australian Meat Processor 3 (AMP3)

This plant is 95% export market with major markets into the Middle East and the EU. Product is predominantly chilled into EU and Asia, heavy weight carcasses into

USA and frozen product to Middle East. Discussion was held with the marketing team and the on-site staff.

This plant already believes that they produce a high quality product that has earned a reputation of quality through their branding, packaging and specifications.

- This technology could be for Niche market products only.
- Would this technology result in product downgrade to product deemed low tenderness?
- Has the possibility to work backwards to the farmer.
- Delivery needs to be across the supply chain to adopt this technology: from farmer to meat processor to those who buy the meat.
- Their main priority is to maintain continued labour supply that is also efficient. Could this technology provide such an advantage?
- They question that this technology would provide merely an additional cost for no real benefit.
- This technology would need to be consumer driven. But they would most likely question what they would have to pay for it.
- In conclusion they don't believe there was enough benefit for this technology.

New Zealand Meat Processor 4 (NZMP4)

Processor 4 is a multiple plant company supplying predominantly export lamb - a mix of frozen and chilled. They have adopted several new on-line technologies in the last 5 years. We believe that they may be a suitable candidate to try prototype NMR systems in the future. Currently this processor grades carcasses on size and fat depth at the end of the slaughter floor.

The following points were raised:

- Company is looking for a technology to reduce the variance of the product.
- Preferably a technology that allows intervention and correction of product
- As much as possible the technology should fit in to existing processes (can't re-engineer all processes)
- Since they are batch processing, have to make some averaging
- If the process was fully automated, they could treat carcasses as individuals
- Any technology that gives meat quality information would be advantageous to the company, and would be looked at.
- The company is interested in measuring meat quality attributes such as drip loss and consumer colour.
- On-line at the end of the slaughter floor would be best

- Have a Tenderness Program
- Tenderness is less of an issue in chilled lamb, where colour and drip are more of an issue
- But still want techniques to control and predict tenderness.
- They feel that they definitely need to be doing something about meat quality to achieve a higher retail value
- A method of predicting ultimate pH (esp. in hot boning beef plant) would be valuable.
- Opportunity to reduce labour in lamb processing, less so in beef and venison
- On-line technology has less use in beef because current grading is based more on carcass conformation – so a camera or X-ray may be better
- Main Benefits: Classify carcasses to provide a more homogenous product for retail and specific markets
- Possible marketing tool? UK superior Product – sticker for “measured as tender” to guarantee consumer satisfaction. May get ~5% more per kilo
- Use of the technology:
    - Pre rigor or just after rigor within the carcass area, although there may be opportunities at the breakdown area of the slaughterhouse
    - Fairly close to grading/end of the chain as this is when decisions are made about where to send the products.
    - Boning room may be too late
    - Gives an opportunity for post rigor measurements, X-Ray etc. Quality can’t be assessed until rigor occurs
- Traceability is vital
- Reducing variability will be the key, getting rid of outliers, improving consistency and standardization of all carcasses.
- Possibility to use as feedback to farmers based on colour, pH
- Need to step up to get to the high end of the market and to reward farmers.
- Need to ensure pricing signals aren’t counter productive. Farmers need to know that they can improve. It shouldn’t be out of their reach.

New Zealand Meat Processor 5 (NZMP5)

Processor 5 is also a multiple plant company supplying predominantly frozen export lamb. They have adopted several new on-line technologies in the last 5 years. We believe that they may also be a suitable candidate to try prototype NMR systems in the future. Currently this processor grades carcasses on size and fat depth at the end of the slaughter floor.

The following points were raised:

- Key benefit is: Feedback tool for suppliers. Assist with the whole process/genetic selection to have better animals
- Signals back to the suppliers will improve consistency within carcasses
- Have a tenderness program in place; however, it involves relatively small number of samples compared to throughput and focuses on processing effects. Costs company about 2000 back straps plus labour cost of running program.
- Slaughter floor is best place for technology (both sheep and beef). After this the carcasses are split up. And this is the point where other data is captured and where grading and decision making occurs.
- If it's a feedback tool, the technology doesn't have to be online
- If decision making tool then it needs to be online
- Key attributes to predict: ultimate pH, tenderness, colour stability
- Drip loss – a lot of product is sent frozen so drip loss isn't a major issue.
- Even in chilled product, given other priorities (grade, weight and to be farm assured) we probably couldn't do anything about it.
- Online technologies could provide a marketing advantage, although this would only last until all the other processors had the same technology.
- Success also depends on the message/slogan. How to draw attention to the product
- Branded with stickers "Tender"? There is potential. Although if this is claimed then justified systems need to be there to back this up. There are other options to guarantee tenderness. If it's a validated methodology then yes this could be done.
- What is an acceptable cost? The amount needs to be justified and hence depends on payback. Within a year is optimum.
- Already within the company there is a drive towards meat quality testing mainly in the areas of yield, tenderness and colour display life. A lab based instrument may suit yet an online system that can handle whole kills would be better.
- Main thoughts about the use of the technology: Provide feedback to improve production, pH of beef is a very important variable to be monitoring

throughout slaughter houses, keeping out outliers and having consistent products, improving the process.

3. Summary of benefits for on-line NMR systems

From the results of the survey work with NZ and Australian processors, a summary of the potential benefits of the NMR technology was developed. Six potential benefits were recognised and are described below. The first five related specifically to the lamb processing industry and so these benefits were investigated in a full cost/benefit analysis. The sixth benefit, which related to using NMR as a lab-based tool for analysis or research purposes, was not included in the cost/benefit analysis because it is unlikely to result in significant net economic benefits for the industry. However, used in this way NMR may provide other benefits such as faster results and reduced labour costs.

1. Classification tool to consistently put carcasses or cuts into 3 or more quality classes

The opportunity to grade carcasses into quality classes using NMR was identified as a potential benefit by all lamb processors we spoke with. Currently, all processors grade into the chiller immediately post slaughter and would prefer a system that will allow for them to continue this practice. However, the process of chilling can significantly affect meat quality and scanning with NMR to determine meat quality pre-chilling may result in an inaccurate assessment of final meat quality. The current practice of grading into the chiller is potentially a major limitation to the use of NMR systems to grade carcasses.

From a meat quality perspective, the NMR system would be best implemented post-chilling, perhaps during transfer to the boning room. A promising system currently used by NZMP4 involves all carcasses go into a ‘holding chiller’ immediately post processing where all carcasses are chilled together for roughly 5 hours. Subjecting carcasses to the same chilling regime will reduce the variability in eating quality due to the chilling regime. After the 5 h period the carcasses are then graded and put in different chillers. The grading system currently grades on carcass weight and fat depth but has the potential to also grade for quality. This system would be ideal to use in conjunction with NMR because carcasses leaving the holding chiller will have entered rigor and the most significant meat quality changes made by the chilling regime should have occurred.

2. Upgrading tool to identify lower value carcasses that are good enough to sell into higher value markets

An example of how NMR systems could identify carcasses in this manner was highlighted by AMP1. Currently they have 2 classification systems for their lamb product: 1) Merino product (perceived to be poorer quality) and 2) Cross bred product (higher quality). They believed that NMR might offer them the ability to upgrade high quality merino product into the cross bred category. This processor felt that the financial benefits of this practice would justify the cost of NMR technologies.

3. Filtering tool to pick out a small % of poor quality carcasses to ensure they do not go to discerning customers

All the processors interviewed felt they had a product with a perceived high level of quality. They believed that the opportunity to remove those carcasses shown by in-house NMR testing to have low tenderness would give them a significant industry advantage. They also felt that this would ensure the continued perception of lamb as a high quality product and would have follow through benefits for the lamb industry as a whole.

There was mixed feeling if the opportunity to ‘assure quality’ would allow processors to demand a premium. AMP2 did not think there would be this opportunity as the ‘cost-price-squeeze’ nature of the Australian lamb industry driven by the two leading supermarket chains would not support a product with a premium. However, the export plants, particularly those selling product into the ‘richer’ EU countries, believed that they may be able to get a premium if they were to assess meat quality with NMR. On the downside, one Australian plant believed that they would have to downgrade the product assessed as poor quality and that this would have significant repercussions for their markets. Other plants did not think the poorer quality product would demand a lower price, especially if the testing remained in-house.

This process of selecting out the poorer quality carcasses would be best conducted post-chilling upon entry into the boning room as much of the meat quality is set by this time. The small percentage of poorer quality carcasses could be separated and detained and then processed for less discerning markets at a later stage.

Each processor we spoke with had a unique approach for how they would use NMR to derive this benefit. For example, AMP1 felt that they could use this technology to process lamb into markets depending on cooking style; for example, regions in which the cooking style involved boiling/stewing meat for longer periods (e.g. Middle Eastern countries) could receive the poorer quality cuts, whereas those who grill meat (e.g. Asian countries) could receive the higher quality cuts. AMP2 felt this tool could differentiate the high quality carcasses for the premium markets such as Australian department store David Jones. This finding highlights the need to work with processors on an individual level to adapt the NMR technology to suit their plant and marketing specifications.

4. Feedback tool to producers and processors, leading to improved quality over time by better genetic selection and improving finishing regimes

Both NZMP5 and AMP3 believed that in-house assessment of meat quality would be a valuable tool to improve the overall quality of their product by allowing feedback to farmers. Firstly, they believed significant gains could be made through large scale on-line phenotypic measurements (e.g. meat quality assessed by NMR) leading to genetic selection for improved meat quality. This is similar to the VIAscan system used by some Australian and NZ processors to assess lean meat yield on-line, which is reported to have led to significant improvements since installation. An on-line measurement system could also potentially identify producers who are not correctly feeding their stock and processors felt they could then work with the farmers to improve their farming practices, leading to improved meat quality.

As a feedback tool, the timing of the measurement is less important because processing decisions do not depend on the result. However, processors still expressed a desire to measure quality prior to chilling. As previously mentioned, from a meat quality perspective, the assessment would be more accurate post-chilling and just before boning.

The system would need to link in with some sort of electric tag/bar coding system. The carcass would be assessed and results processed through a CPMS system. There may be the opportunity to link the NMR system up with equipment assessing carcass composition such as VIAscan or even to CT technologies currently being evaluated for use in robotic boning.

AMP3, NZMP4 and NZMP5 believed that a producer payment system dependent on the NMR assessed carcass quality was probably not suitable.

Any in-house test of meat quality would also provide feedback to the plant itself. The systems may identify any problems within a plant, such as inadequate stimulation or a chilling regime that is too fast, and would demonstrate areas where meat quality may be improved. Providing a benchmark and ongoing monitoring would allow the lamb processor to judge and control their tenderness and should result in a reduction in the variation in meat quality.

5. Marketing tool to allow retailers and wholesalers to sell product on "measured as tender" basis

AMPP2 and AMP3 felt that one of the ways to get plants to implement this technology was to make the push through the supermarket chains in particular. This marketing approach was only considered possible in vertically integrated supply chains (i.e. where there is a close established link between producers, processors and retailers). In situations where there was less vertical integration, processors were concerned that retailers either may not market the product effectively (leading to a loss of the benefit) or may not pay a premium for the product. One other issue may be the fact that the technology should not be mentioned to consumers, because a meat product assessed by ‘nuclear magnetic radiation’ may not have a positive connotation for the public.

Despite these challenges, all the processors believed that with the right promotion consumers would be prepared to pay some level of premium for product that has assured tenderness and most processors also believed that the perception of lamb as a high quality product would be improved.

NMR may have potential to enhance the Australian MSA beef and sheepmeat grading system. There are two clear possibilities for potential improvements: 1) to reduce the cost of grading by doing it faster or with less labour, or 2) to improve the accuracy of grading.

6. NMR may be a valuable tool for facilitating in-house, laboratory and research meat quality testing

NZMP5 and the research team from AgResearch and Murdoch University believed that NMR may have potential to replace conventional shear force testing using the Warner-Bratzler or MIRINZ tenderometer systems. Reducing the required meat sample size and reducing the time to measure by eliminating the need to cook the samples, etc. Evidence in the scientific literature also indicates that NMR may be able to measure water holding capacity or predict drip loss from meat.

Many lamb processors conduct in-house testing for objective meat quality traits such as tenderness, drip loss and pH. The use of NMR in place of conventional systems may make testing both simpler and quicker. This may also encourage other processors, who do not currently conduct in-house testing, to start. More regular measurement of meat quality throughout the industry should lead to a reduction in variation and an improvement in quality.

4. Summary of Cost/Benefit Analysis

A full cost/benefit analysis was carried out (given in Appendix 2). The input data, assumptions and results of the analysis are outlined below. The analysis focused only on lamb and did not consider mutton or meat from other species because the R&D project is currently focused on lamb. In terms of estimated economic benefits, Australia and NZ were considered separately in order to more accurately define the way in which NMR might be applied in both countries. However, both countries were combined together when the R&D and implementation costs were estimated (because these are currently being shared). Therefore, the results of the cost/benefit analysis reflect the estimated net economic benefits for both countries combined.

4.1 Estimated Benefits for New Zealand

(Calculations carried out in NZ$)

Input Data

Data on the value and volume of lamb exported from NZ to the top 94 overseas markets in 2005/06 was sourced from Statistics New Zealand. Therefore, the benefits to NZ focused only on export lamb and excluded mutton and any domestically sold product. Since export lamb dominates NZ production, this assumption was considered acceptable and conservative.

Total # of major plants = 35

Total volume lamb exported = 311,000 tonne

Total value of exported lamb = NZ$ 2117 million

Top 94 export markets could be categorised into high, med and low value markets:

Market Value	**Classifier**	**% of total volume**	**Mean value** (per tonne)
High	>$8000/t	28%	$9,400
Medium	>$5000/t but <$8000/t	55%	$6,070
Low	<$5000/t	17%	$4,700

Top 94 export markets can also be categorised into high and med/low value:

Market Value	**Classifier**	**% of total volume**	**Mean value** (per tonne)
High	>$8000/t	28%	$9,400
Medium/Low	<$8000/t	72%	$5,760

Assumptions to Quantify Benefits in NZ

The most critical assumption for the benefit analysis was that the NMR technology is able to work in each of the application areas identified by the processors interviews. Although this is technically not likely it is a necessary assumption in order to quantify the potential benefits. The assumptions relating to each benefit, including the estimated uptake by NZ processors are given below.

a) Classification tool

- We have assumed that there are 3 'quality classes' that match to the three different markets and that NMR can help to match product quality to market requirements.
- We have assumed that each market is supplied with a mix of each quality class, so that the product quality in each class is variable.
- The % of consumers in most the high value market (i.e. the most discerning) that will not buy again after several inconsistent experiences is estimated to be 10%.
- The % of consumers in medium value market that will not buy again after several inconsistent experiences is estimated to be 2%.
- The % of consumers in low value market that will not buy again after several inconsistent experiences is estimated to be 0.5%.
- Although it is likely that consumers in the medium or low value markets would be happy receiving higher quality product, since the quality of the product is variable then their expectations are unlikely to be consistently met.
- NZMP4 was interested in applying NMR to achieve benefit (a); it was assumed likely that at least 5 NZ plants out of 35 would take up NMR for this purpose.

b) Upgrading tool

- We have assumed that some medium and lower value products are good enough to be upgraded to higher value markets and that NMR can identify these.
- We have assumed the % of lower value product that is good enough to be sold into higher value markets is 5%.
- We have assumed that demand is high enough in the higher value market to sustain more product supply without altering price negatively.
- It was assumed that only 2 NZ plants out of 35 will use NMR in this way.

c) Filtering tool

- The % of consumers in the high value markets (i.e. most discerning) that would not buy again after several inconsistent experiences is estimated to be 10%.
- We have assumed the technology can identify medium and lower value products to ensure none of this product enters the high value markets, thereby ensuring customers in the high value markets get a consistent eating experience and the number of repeat purchases are maximised.
- It was conservatively assumed that only 3 NZ plants out of 35 will use NMR in this way.

d) Feedback tool

- It was assumed that using NMR as a feedback tool could change the proportion of product in each quality class over time, increasing the high and medium value and reducing the lower value.
- We have assumed that demand is high enough in high and medium value markets to sustain the shift in product supply without affecting the price negatively.
- It was assumed that it would take three years in order to alter the proportion of product in each quality class.
- The assumed new market split after 3 years of using the tool was:
  - □ High value = 32% (up by 4%)
  - □ Medium value = 58% (up by 3%)
  - □ Low value = 10% (down by 7%)
- NZMP5 was interested in applying NMR to achieve benefit (d); it was assumed that 3 NZ plants out of 35 would take up NMR for this purpose.

e) Marketing tool

- We have assumed that NMR could provide the ability to market lamb to consumers on a "measured as tender" basis.
- We have assumed that consumers in the high and medium markets will pay a premium for this product.
- The assumed premium for "measured as tender" lamb was NZ$ 500 per tonne.
- There are not that many processors in NZ that have a completely vertically integrated supply chain so we have assumed that only 1 plant out of 35 will take up NMR and gain this benefit.

4.2 Estimated Benefits in Australia

(Calculations carried out in A$)

Input Data

The Australian cost benefit analysis focused on both export and domestic lamb (the analysis excluded mutton). The figures obtained from ABARE and MLA (Anon, 2006) indicated that A$ 1.2 billion of the sheep industry's A$ 1.9 billion revenue came from lamb meat exports and lamb meat domestic sales.

Total # of major plants = 30: (In Australia the top 30 lamb processors dominate 80% of the industry).

Number of export lamb plants: 20

Number of domestic lamb plants: 10

Proportion of export production verses domestic production: 50:50

Total volume lamb exported = 175,000 tonne

Total volume of domestic lamb = 175,000 tonne

Total value of exported lamb = A$ 822 million

Total value of domestic lamb = A$ 400 million

Export markets could be categorised into high, medium and low value markets:

Market Value	**Classifier**	**% of total volume**	**Mean value** (per tonne)
High	>$6500/t	38%	$7,000
Medium	>$3000/t but <$6500/t	43%	$4,200
Low	<$3000/t	19%	$2,000

Export markets can also be categorised into high and medium/low value:

Market Value	**Classifier**	**% of total volume**	**Mean value** (per tonne)
High	>$6500/t	38%	$7,000
Medium/Low	<$6500/t	62%	$4,000

Domestic markets could be categorised into high, medium and low value markets:

Market Value	**Classifier**	**% of total**	**Mean value**

		volume	(per tonne)
High	>$3000/t	20%	$3,500
Medium	>$2000/t but <$3000/t	40%	$2,400
Low	<$2000/t	40%	$1,700

Domestic markets can also be categorised into high and medium/low value:

Market Value	**Classifier**	**% of total volume**	**Mean value** (per tonne)
High	>$3000/t	20%	$3,500
Medium/Low	<$2000/t	80%	$2,000

Assumptions

Similar assumptions to those made in the NZ model were also used for the Australian model. The most critical assumption for the benefit analysis was that the NMR technology is able to work in each of the application areas identified by the processors interviews. The assumptions relating to each benefit, including the estimated uptake by Australian processors are given below.

a) Classification tool

- We have assumed that there are 3 'quality classes' that match to the three different markets and that NMR can help to match product quality to market requirements.
- This assumption of proportions and values for the export market was derived from examining sales going to high value markets such as the EU and USA, Low value markets such as Papua New Guinea and China and everything else in between considered medium value markets. Figures for these values and amounts were available for 2006.
- For the domestic markets: there is a demand for budget meat so values and proportions per market were adjusted accordingly.
- We have assumed that each market is supplied with a mix of each quality class, so that the product quality in each class is variable.
- The % of consumers in the high, medium and low value markets that will not buy again after several inconsistent experiences is estimated to be 10%, 2% and 0.5% respectively.
- Although it is likely that consumers in the medium or low value markets would be happy receiving higher quality product, since the quality of the product is variable then their expectations are unlikely to be consistently met.

- Both AMP1 and AMP2 expressed a desire to use the NMR for this purpose; therefore, 2 out of the 20 export plants and 1 out of the 10 domestic plants were predicted to uptake NMR for this purpose.

b) Upgrading tool

- We have assumed that some medium and lower value products are good enough to be upgraded to higher value markets and that NMR can identify these. In Australia a significant opportunity lies in upgrading the proportion of high quality merino lamb, currently considered a lower value product.
- We have assumed the % of lower value product that is good enough to be sold into higher value markets is 5%.
- We have assumed that demand is high enough in the higher value market to sustain more product supply without altering price.
- AMP1 believed this benefit would be a valuable opportunity and this company currently operates 2 plants and are upgrading further plants. Hence, we believe 4 export plants and 1 domestic plant would uptake NMR for this purpose.

c) Filtering tool

- The % of consumers in the high value markets (i.e. most discerning) that would not buy again after several inconsistent experiences is estimated to be 10%.
- We have assumed the technology can identify medium and lower value products to ensure none of this product enters the high value markets, thereby ensuring customers in the high value markets get a consistent eating experience and the number of repeat purchases are maximised.
- It was conservatively assumed that 3 plants (2 export and 1 domestic) would uptake NMR for this purpose.

d) Feedback tool

- It was assumed that using NMR as a feedback tool could change the proportion of product in each quality class over time, increasing the high and medium value and reducing the lower value.
- We have assumed that demand is high enough in high and medium value markets to sustain the shift in product supply without affecting the price negatively.
- It was assumed that it would take three years in order to alter the proportion of product in each quality class.

- The assumed new export market split after 3 years of using the tool was:
  - High value = 42% (up by 4%)
  - Medium value = 46%(up by 3%)
  - Low value = 12% (down by 7%)
- The assumed new domestic market split after 3 years of using the tool was:
  - High value = 24% (up by 4%)
  - Medium value = 43%(up by 3%)
  - Low value = 33% (down by 7%)
- It was assumed that 3 export and 1 domestic plant would take up NMR for this purpose.

e) Marketing tool

- We have assumed that NMR could provide the ability to market lamb to consumers on a "measured as tender" basis.
- We have assumed that consumers in the high and medium markets will pay a premium for this product.
- The assumed premium for "measured as tender" lamb was A$ 500 per tonne.
- AMP3 actively give feedback to processors and indicated that they would be interested in using NMR for this purpose. We expect that 2 export and 2 domestic plants would uptake NMR for this purpose.

4.3 Estimated costs for Australia and NZ

(Calculations carried out in NZ$)

The R&D phase is expected to last 6 years. The estimated R&D costs are NZ$ 250,000 p.a. for years 1 to 4 and NZ$ 750,000 p.a. for years 5 to 6. This assumes that a significant amount will need to be spent in years 5 and 6 in order to fund development of on-line NMR.

It was assumed uptake of NMR will begin after year 6 and that the technology will be steadily taken up over a period of 4 years (i.e. rising by 25% each year until reaching 100% of maximum uptake levels in year 10). It was assumed that benefits will start to accrue at same rate as technology uptake, except for benefit (d) (NMR as a feedback tool), which we have assumed will take three years to result in benefits.

The maximum number of plants assumed to uptake NMR in NZ was 14 out of 35 plants. The maximum number of plants assumed to uptake NMR in Australia was19 out of 30 plants. This is a total of 33 plants across Australia and NZ.

It was assumed that each plant will require four NMR machines at a cost of NZ$ 100,000 per machine when they uptake the technology. This gives an assumed capital investment of NZ$ 400,000 per plant. It was assumed that the equipment will require operating and maintenance costs of NZ$ 10,000 per machine each year (i.e. NZ$ 40,000 per plant each year).

4.4. Cash flow, Net Present Value and Internal rate of Return

(Calculations carried out in NZ$)

At maximum uptake levels the individual benefits are estimated to return the following to the NZ and Australian lamb processing industries:

a) Classification tool – NZ$ 18.0 million p.a. from year 10

b) Upgrading tool – NZ$ 10.8 million p.a. from year 10

c) Filtering tool – NZ$ 9.7 million p.a. from year 10

d) Feedback tool – NZ$ 16.0 million p.a. from year 13

e) Marketing tool – NZ$ 16.7 million p.a. from year 10

Assuming all the benefits are achieved, the net cash flow (benefits minus costs) after tax (commercial tax rate assumed to be 30%) is:

Year ending	Net cash flow
2007	-$250,000
2008	-$250,000
2009	-$250,000
2010	-$250,000
2011	-$750,000
2012	-$750,000
2013	$7,114,000
2014	$16,537,000
2015	$25,961,000
2016	$38,186,000
2017	$43,296,000
2018	$46,097,000
2019	$48,897,000
2020	$48,897,000

2021	$48,897,000
2022	$48,897,000
2023	$48,897,000
2024	$48,897,000
2025	$48,897,000
2026	$48,897,000

The above cash flow gives a net present value (NPV) of NZ$148 million (or A$129 million at exchange rate of 0.87) and an internal rate of return (IRR) of 98%. These are phenomenal returns and we believe that they are unrealistic because it is unlikely that the NMR technology will be able to successfully achieve all the potential benefits outlined in the cost/benefit analysis.

If we assume that only one of the benefits could be achieved with the NMR technology (say benefit (a) – the classification tool), the cash flow is altered significantly, the NPV becomes NZ$ 34 million and the IRR becomes 60%. This indicates that NMR is still an excellent investment if only this one benefit can be successfully achieved.

5. Conclusions

The industry consultation identified six potential benefits that NMR could provide for the Australian and NZ lamb processing industry. Five of these were expected to provide significant economic benefits and were therefore included in a cost/benefit analysis.

The cost/benefit analysis was carried out using published industry data and by making several assumptions about the costs, benefits and uptake of the NMR technology across the Australian and NZ lamb processing industry. The most significant assumption in the cost/benefit analysis was that the NMR technology could actually be used to achieve all the benefits identified by the industry consultation. If this was the case, the NMR project was estimated to have a net present value (NPV) of NZ$148 million (or A$129 million at exchange rate of 0.87) and an internal rate of return (IRR) of 98%.

However, we believe it is unlikely that NMR could provide all of these benefits. The cost/benefit analysis was recalculated assuming that only one of the identified benefits could be provided by NMR. This reduced the NPV to NZ$ 34 million and the IRR to 60%. This recalculation indicated that NMR is still an excellent investment if only this one benefit can be successfully achieved.

Appendix 1:

Description of NMR, outline of project aims and likely question list sent to processors before interviews were conducted

MIRINZ Food Technology & Research Inc.
MIRINZ Inc.

mla
MEAT & LIVESTOCK AUSTRALIA

MURDOCH UNIVERSITY
PERTH, WESTERN AUSTRALIA

agresearch Farming, Food and Health. First
Te Ahuwhenua, Te Kai me te Whai Ora. Tuatahi

Measurement of meat quality

Requirements to an online measurement system

Meat & Livestock Australia (MLA) and MIRINZ Inc are currently targeting research into online measurement systems for the evaluation of meat quality. MLA and MIRINZ Inc have contracted Murdoch University and AgResearch to work on a joint Australia and NZ project in this area.

We are currently investigating low field nuclear magnetic resonance (NMR relaxometry) as a potential on-line measurement system. NMR is non-invasive and non-destructive, which are essential requirements for any on-line measurement system. NMR relaxometry is a unique technology for studying meat quality, because it gives direct information about the water properties within the muscle. Because of the non-destructive nature of NMR, the technique has been demonstrated to be an excellent tool for studying 1) the conversion of muscle to meat and 2) how intrinsic factors (e.g. species, genotype, muscle type) and technological factors (e.g. slaughter procedure, cooling regime, storage) affect the water characteristics within the meat and thereby the meat quality. For example, NMR measurements on pork can distinguish between meat classified as PSE (pale, soft and exudative), normal or DFD (dark, firm and dry). NMR has also proven successful in determination of fat and water-holding capacity of meat and, in addition, results found in our current project indicate that NMR can predict meat tenderness.

The NMR research reported by other institutes used commercially-available “bench-top” LF-NMR instruments, which require small meat samples to be excised and placed into a sealed chamber for measurement. We do not consider these instruments feasible to use for online measurements of meat quality. However, open-topped NMR systems, where a whole carcass or cut could be placed on top on the instrument for measurement without excising a sample, are under development as part of this project.

Online meat quality measurements systems could have the potential to

1. Assure the quality of your product through process control
2. Support a carcass-trading system based on the quality of each carcass
3. Allow segregation of product into quality or export/domestic lines.

We are interested in your views about the potential for online measurement systems in general. Your comments on the following questions will assist us in developing this technology.

1. Do you believe online grading systems have a role in the Australian/New Zealand meat processing industry?
2. Do you believe NMR technology could have the potential to be used as an online grading system?
3. How do you perceive NMR technology could be used?
4. Who would use this technology?
5. What specific attributes would you want to use this technology to evaluate?
6. Where in the processing chain could you use this technology? Pre or post rigor? On the slaughter floor?
7. What value would you place on being able to classify your meat for quality?
8. What value would you place on being able segregate your product into different quality classes such as splitting product into domestic, air or sea freight international (long or short ageing) lines?
9. Do you believe incorporating this technology could have a marketing advantage for you?
10. How much money would you be willing to spend on this technology
11. What are the export and domestic product applications?
12. Would retailers want meat processors to segregate meat products?
13. Would tenderness be a valuable attribute to measure?
14. Would you assess tenderness post rigor in the boning room and possibly segregate product at this point?
15. What impact would it have on feedback mechanisms: from the retailer to the farmer?

Appendix 2:

Microsoft Excel™ spreadsheet showing full cost/benefit analysis

Common Data

Discount rate used:	10% per annum
Corporate tax rate:	30% as from 1 July 2008 in NZ

All calculations are based in NZ$ unless otherwise specified

NZ Data

Export lamb only

Figures from 2005/06 by market (source Statistics NZ)

Total volume	311,000	tonne
Total value	2117	NZ$ million
Total # of major plants	35	plants
Total estimated NMR uptake	14	plants

Top 94 export markets can be categorised into high, med and low value:

	Classifier	% of total volume	Mean value	
High	>$8000/t	28%	$9,400	per tonne
Medium	>$5000/t but <$8000/t	55%	$6,070	per tonne
Low	<$5000/t	17%	$4,700	per tonne

Top 94 export markets can also be categorised into high and med/low value:

	Classifier	% of total volume	Mean value	
High	>$8000/t	28%	$9,400	per tonne
Med/low	<$8000/t	72%	$5,760	per tonne

Australian Data

Export and domestic lamb only

Figures from: 'Australian Lamb: Slaughter lamb industry report 06' by ABARE and MLA

Total volume of lamb produced	350,000	tonne		
Total value of lamb industry	1222	A$ million		(excluding live export and mutton)
Proportion exported:domestic	50%		50%	
Total export volume	175000	tonne		
Total value of exports	822	A$ million		
Total domestic volume	175000	tonne		
Total value of domestic	400	A$ million		
Conversion factor	0.87	NZ$/A$		
Total value of exports	945	NZ$ million		
Total value of domestic	460	NZ$ million		
Total # of major export plants	20	plants		
Total estimated export uptake	13	plants		
Total # of major domestic plants	10	plants		
Total estimated domestic uptake	6	plants		

Top export lamb markets can be categorised into high, med and low value:

	Classifier	% of total volume	Mean value	
High	>$6500/t	38%	$7,000	per tonne
Medium	>$3000/t but <$6500/t	43%	$4,200	per tonne
Low	<$3000/t	19%	$2,000	per tonne

Top export markets can also be categorised into high and med/low value:

	Classifier	% of total volume	Mean value	
High	>$6500/t	38%	$7,000	per tonne
Med/low	<$6500/t	62%	$4,000	per tonne

Top domestic lamb markets can be categorised into high, med and low value:

	Classifier	% of total volume	Mean value	
High	>$3000/t	20%	$3,500	per tonne
Medium	>$2000/t but <$3000/t	40%	$2,400	per tonne
Low	<$2000/t	40%	$1,700	per tonne

Top domestic markets can also be categorised into high and med/low value:

	Classifier	% of total volume	Mean value	
High	>$3000/t	20%	$3,500	per tonne
Med/low	<$2000/t	80%	$2,000	per tonne

Benefits - NZ

All amounts in NZ$

There are five benefits to be gained from this project if successful:

a) Classification tool to consistently put carcasses or cuts into 3 or more quality classes
b) Upgrading tool to identify lower value carcasses (e.g. merino) that are good enough to sell into higher value markets
c) Filtering tool to pick out small % of poor quality carcasses to ensure they do not go to discerning customers
d) Feedback tool to producers and processors, leading to improved quality over time by better genetic selection, finishing, etc
e) Marketing tool to allow retailers and wholesalers to sell product on "measured as tender" basis

a) Classification tool

Assume there are 3 'quality classes' matching three different markets - technology can help match product quality to market requirements

Expected uptake by industry		5 plants out of	35 plants	
Industry throughput of		311000 tonne of export lamb/pa		
Market 1	Value=	$9,400 $/t	% product=	28%
Market 2	Value=	$6,070 $/t	% product=	55%
Market 3	Value=	$4,700 $/t	% product=	17%
Current value of markets serviced by participating plants =			$300,759,214	

Assumptions:

% of consumers in most discerning market that will not buy again after several inconsistent experiences=	10%
% of consumers in middle market that will not buy again after several inconsistent experiences=	2%
% of consumers in lower market that will not buy again after several inconsistent experiences=	0.5%
Expected loss in repeat sales due to inconsistent quality =	$11,985,255 per annum
Assuming the technology can consistently classify product into the correct market requirement, the benefit =	$11,985,255 per annum

b) Upgrading tool

Assume that some lower value products are good enough to be upgraded to higher value markets, the technology can identify these

Expected uptake by industry		2 plants out of	35 plants	
Industry throughput of		311000 tonne of export lamb/pa		
Market 1	Value=	$9,400 $/t	% product=	28%
Market 2	Value=	$5,760 $/t	% product=	72%
Current value of markets serviced by participating plants =			$120,476,069	

Assumptions:

% of lower value product that is good enough to be sold into higher value markets= 5%
Assume that demand is high enough in higher value market to sustain more product supply
Same value but new market split:

Market 1	Value=	$9,400 $/t	% product=	33%
Market 2	Value=	$5,760 $/t	% product=	67%
New value of markets serviced by particpating plants =			$123,710,469	

Assuming the technology can identify product good enough to sell into higher value markets, the benefit = $3,234,400 per annum

c) Filtering tool

Assume the technology can "weed out" lower value carcasses to improve consistency for discerning markets

Expected uptake by industry		3 plants out of	35 plants	
Industry throughput of		311000 tonne of export lamb/pa		
Market 1	Value=	$9,400 $/t	% product=	28%
Market 2	Value=	$6,070 $/t	% product=	55%
Market 3	Value=	$4,700 $/t	% product=	17%
Current value of markets serviced by participating plants =			$180,455,529	

Assumptions:

% of consumers in most discerning market that will not buy again after several inconsistent experiences=	10%
Expected loss in repeat sales due to inconsistent quality =	$5,052,755 per annum
Assuming the technology can consistently "weed out" lower quality product, the benefit =	$5,052,755 per annum

d) Feedback tool

Assume that the technology can be used to move more product into higher value markets over time

Expected uptake by industry		3 plants out of	35 plants	
Industry throughput of		311000 tonne of export lamb/pa		
Market 1	Value=	$9,400 $/t	% product=	28%
Market 2	Value=	$6,070 $/t	% product=	55%
Market 3	Value=	$4,700 $/t	% product=	17%
Current value of markets serviced by participating plants =			$180,455,529	

Assumptions:

Assume that demand is high enough in higher value markets to sustain shift in product supply

Same value but new market split:					Change
Market 1	Value=	$9,400 $/t	% product=	32%	4%
Market 2	Value=	$6,070 $/t	% product=	58%	3%
Market 3	Value=	$4,700 $/t	% product=	10%	-7%
New value of markets serviced by particpating plants =			$186,562,680		

Assuming the technology can provide the feedback leading to this outcome, the benefit = $6,107,151 per annum

e) Marketing tool

Assume that technology provides system to market to consumers on "measured as tender" basis

Expected uptake by industry		1 plants out of	35 plants	
Industry throughput of		311000 tonne of export lamb/pa		
Market 1	Value=	$9,400 $/t	% product=	28%
Market 2	Value=	$6,070 $/t	% product=	55%
Market 3	Value=	$4,700 $/t	% product=	17%
Current value of markets serviced by participating plants =			$60,151,843	

Assumptions:

Assume that product in high and middle markets can be sold for a premium
Premium for "measured as tender" = $500 $/t

New value but same market split:

Market 1	Value=	$9,900 $/t	% product=	28%
Market 2	Value=	$6,570 $/t	% product=	55%
Market 3	Value=	$4,700 $/t	% product=	17%
New value of markets serviced by particpating plants =			$63,839,414	

Assuming the technology can provide the feedback leading to this outcome, the benefit = $3,687,571 per annum

Benefits - Australia

All amounts in A$

There are five benefits to be gained from this project if successful:

a) Classification tool to consistently put carcasses or cuts into 3 or more quality classes
b) Upgrading tool to identify lower value carcasses (e.g. merino) that are good enough to sell into higher value markets
c) Filtering tool to pick out small % of poor quality carcasses to ensure they do not go to discerning customers
d) Feedback tool to producers and processors, leading to improved quality over time by better genetic selection, finishing, etc
e) Marketing tool to allow retailers and wholesalers to sell product on "measured as tender" basis

a) Classification tool

Assume that there are 3 'quality classes' that match to three different markets - technology can help to match product quality to market requirements

LAMB EXPORT

Expected uptake by industry		2 plants out of	20 plants			
Industry throughput of		175000 tonne of lamb/pa				
Market 1	Value=	$7,000 $/t (AUS$)	% product=	38%	High	>$6500/t
Market 2	Value=	$4,200 $/t	% product=	43%	Medium	>$3000/t but <$6500/t
Market 3	Value=	$2,000 $/t	% product=	19%	Low	<$3000/t
Current value of markets serviced by participating plants =		$84,805,000				

Assumptions:

% of consumers in most discerning market that will not buy again after several inconsistent experiences=	10%
% of consumers in middle market that will not buy again after several inconsistent experiences=	2%
% of consumers in lower market that will not buy again after several inconsistent experiences=	0.5%
Expected loss in repeat sales due to inconsistent quality =	$4,032,478 per annum
Assuming the technology can consistently classify product into the correct market requirement, the benefit =	$4,032,478 per annum

LAMB DOMESTIC

Expected uptake by industry		1 plants out of	10 plants			
Industry throughput of		175000 tonne of lamb/pa				
Market 1	Value=	$3,500 $/t (AUS$)	% product=	20%	High	>$3000/t
Market 2	Value=	$2,400 $/t	% product=	40%	Medium	>$2000/t but <$3000/t
Market 3	Value=	$1,700 $/t	% product=	40%	Low	<$2000/t
Current value of markets serviced by participating plants =		$40,950,000				

Assumptions:

% of consumers in most discerning market that will not buy again after several inconsistent experiences=	10%
% of consumers in middle market that will not buy again after several inconsistent experiences=	2%
% of consumers in lower market that will not buy again after several inconsistent experiences=	0.5%
Expected loss in repeat sales due to inconsistent quality =	$1,228,500 per annum
Assuming the technology can consistently classify product into the correct market requirement, the benefit =	$1,228,500 per annum

Assuming the technology can consistently classify product into the correct market requirement for both EXPORT AND DOMESTIC, the benefit = $5,260,978

b) Upgrading tool

Assume that some lower value carcasses are good enough to be upgraded to higher value markets, the technology can identify these

LAMB EXPORT

Expected uptake by industry		4 plants out of	20 plants	
Industry throughput of		175000 tonne of lamb/pa		
Market 1	Value=	$7,000 $/t (AUS $)	% product=	38%
Market 2	Value=	$4,000 $/t	% product=	62%
Current value of markets serviced by participating plants =		$179,900,000		

Assumptions:

% of lower value product that is good enough to be sold into higher value markets= 5%
Assume that demand is high enough in higher value market to sustain more product supply
Same value but new market split:

Market 1	Value=	$7,000 $/t (AUS $)	% product=	43%
Market 2	Value=	$4,000 $/t	% product=	57%
New value of markets serviced by particpating plants =		$185,150,000		

Assuming the technology can identify product good enough to sell into higher value markets, the benefit = $5,250,000 per annum

LAMB DOMESTIC

Expected uptake by industry		1 plants out of	10 plants	
Industry throughput of		175000 tonne of lamb/pa		
Market 1	Value=	$3,500 $/t (AUS $)	% product=	20%
Market 2	Value=	$2,000 $/t	% product=	80%
Current value of markets serviced by participating plants =		$40,250,000		

Assumptions:

% of lower value product that is good enough to be sold into higher value markets= 5%
Assume that demand is high enough in higher value market to sustain more product supply
Same value but new market split:

Market 1	Value=	$3,500 $/t (AUS $)	% product=	25%
Market 2	Value=	$2,000 $/t	% product=	75%
New value of markets serviced by particpating plants =		$41,562,500		

Assuming the technology can identify product good enough to sell into higher value markets, the benefit = $1,312,500 per annum

Assuming the technology can identify product good enough to sell into higher value markets, the benefit = $6,562,500

c) Filtering tool

Assume the technology can "weed out" lower value carcasses to improve consistency for discerning markets

LAMB EXPORT						
Expected uptake by industry			2 plants out of	20 plants		
Industry throughput of			175000 tonne of lamb/pa			
Market 1	Value=	$7,000 $/t (AUS$)	% product=	38%		
Market 2	Value=	$4,200 $/t	% product=	43%		
Market 3	Value=	$2,000 $/t	% product=	19%		
Current value of markets serviced by participating plants =			$84,805,000			
Assumptions:						
% of consumers in most discerning market that will not buy again after several inconsistent experiences=						10%
Expected loss in repeat sales due to inconsistent quality =						$3,222,590 per annum
Assuming the technology can consistently "weed out" lower quality product, the benefit =						$3,222,590 per annum

LAMB DOMESTIC						
Expected uptake by industry			1 plants out of	10 plants		
Industry throughput of			175000 tonne of lamb/pa			
Market 1	Value=	$3,500 $/t (AUS$)	% product=	20%		
Market 2	Value=	$2,400 $/t	% product=	40%		
Market 3	Value=	$1,700 $/t	% product=	40%		
Current value of markets serviced by participating plants =			$40,950,000			
Assumptions:						
% of consumers in most discerning market that will not buy again after several inconsistent experiences=						10%
Expected loss in repeat sales due to inconsistent quality =						$819,000 per annum
Assuming the technology can consistently "weed out" lower quality product, the benefit =						$819,000 per annum

Assuming the technology can consistently "weed out" lower quality product, the benefit = $4,041,590

d) Feedback tool

Assume that the technology can be used to move more product into higher value markets over time

LAMB EXPORTS						
Expected uptake by industry			3 plants out of	20 plants		
Industry throughput of			175000 tonne of lamb/pa			
Market 1	Value=	$7,000 $/t	% product=	38%		
Market 2	Value=	$4,200 $/t	% product=	43%		
Market 3	Value=	$2,000 $/t	% product=	19%		
Current value of markets serviced by participating plants =			$127,207,500			
Assumptions:						
Assume that demand is high enough in higher value markets to sustain shift in product supply						
Same value but new market split:					Change	
Market 1	Value=	$7,000 $/t	% product=	42%	4%	
Market 2	Value=	$4,200 $/t	% product=	46%	3%	
Market 3	Value=	$2,000 $/t	% product=	12%	-7%	
New value of markets serviced by particpating plants =			$134,190,000			
Assuming the technology can provide the feedback leading to this outcome, the benefit =						$6,982,500 per annum

LAMB DOMESTIC						
Expected uptake by industry			1 plants out of	10 plants		
Industry throughput of			175000 tonne of lamb/pa			
Market 1	Value=	$3,500 $/t	% product=	20%		
Market 2	Value=	$2,400 $/t	% product=	40%		
Market 3	Value=	$1,700 $/t	% product=	40%		
Current value of markets serviced by participating plants =			$40,950,000			
Assumptions:						
Assume that demand is high enough in higher value markets to sustain shift in product supply						
Same value but new market split:					Change	
Market 1	Value=	$3,500 $/t	% product=	24%	4%	
Market 2	Value=	$2,400 $/t	% product=	43%	3%	
Market 3	Value=	$1,700 $/t	% product=	33%	-7%	
New value of markets serviced by particpating plants =			$42,577,500			
Assuming the technology can provide the feedback leading to this outcome, the benefit =						$1,627,500 per annum

Assuming the technology can provide the feedback leading to this outcome, the benefit = $8,610,000

e) Marketing tool

Assume that technology provides system to market to consumers on "measured as tender" basis

LAMB EXPORTS						
Expected uptake by industry			2 plants out of	20 plants		
Industry throughput of			175000 tonne of lamb/pa			
Market 1	Value=	$7,000 $/t	% product=	38%		
Market 2	Value=	$4,200 $/t	% product=	43%		
Market 3	Value=	$2,000 $/t	% product=	19%		
Current value of markets serviced by participating plants =			$84,805,000			
Assumptions:						
Assume that product in high and middle markets can be sold for a premium						
Premium for "measured as tender" =			$500 $/t			
New value but same market split:						
Market 1	Value=	$7,500 $/t	% product=	38%		
Market 2	Value=	$4,700 $/t	% product=	43%		
Market 3	Value=	$2,000 $/t	% product=	19%		
New value of markets serviced by particpating plants =			$91,892,500			
Assuming the technology can provide the feedback leading to this outcome, the benefit =						$7,087,500 per annum

LAMB DOMESTIC						
Expected uptake by industry			2 plants out of	10 plants		
Industry throughput of			175000 tonne of lamb/pa			
Market 1	Value=	$3,500 $/t	% product=	20%		
Market 2	Value=	$2,400 $/t	% product=	40%		
Market 3	Value=	$1,700 $/t	% product=	40%		
Current value of markets serviced by participating plants =			$81,900,000			
Assumptions:						
Assume that product in high and middle markets can be sold for a premium						
Premium for "measured as tender" =			$200 $/t			
New value but same market split:						
Market 1	Value=	$3,700 $/t	% product=	20%		
Market 2	Value=	$2,600 $/t	% product=	40%		
Market 3	Value=	$1,700 $/t	% product=	40%		
New value of markets serviced by particpating plants =			$86,100,000			
Assuming the technology can provide the feedback leading to this outcome, the benefit =						$4,200,000 per annum

Assuming the technology can provide the feedback leading to this outcome, the benefit = $11,287,500

Uptake Rate and Estimated Costs

The R&D phase is expected to last:			6	years	
At a cost of:			250000	per year	for yrs 1-4
			750000	per year	for yrs 5-6
Uptake will therefore start after year:			6		
After R&D, the technology will be steadily taken up over a period of:			4	years	
Benefits will start to accrue at same rate as technology uptake					
Maximum number of plants uptaking in NZ			14	plants	
Maximum number of plants uptaking in Australia			19	plants	
Total			33	plants	
Therefore, uptake will reach maximum of	33	plants after year	10		
Benefits will also reach maximum after year	10				
Equipment and implementation costs per plant		CAPEX	$400,000	in 1st year	
		OPEX	$40,000	each year	

Combined costs and benefits for NZ & Australia

Cash flows in NZ$

Year ending	Uptake level	Benefit (a)	Benefit (b)	Benefit (c)	Benefit (d)	Benefit (e)	Total benefits	R&D costs	Equip & implementation costs	Net of costs and benefits	Net C&B after tax
2007	0%	$0	$0	$0	$0	$0	$0	$250,000	$0	-$250,000	-$250,000
2008	0%	$0	$0	$0	$0	$0	$0	$250,000	$0	-$250,000	-$250,000
2009	0%	$0	$0	$0	$0	$0	$0	$250,000	$0	-$250,000	-$250,000
2010	0%	$0	$0	$0	$0	$0	$0	$250,000	$0	-$250,000	-$250,000
2011	0%	$0	$0	$0	$0	$0	$0	$750,000	$0	-$750,000	-$750,000
2012	0%	$0	$0	$0	$0	$0	$0	$750,000	$0	-$750,000	-$750,000
2013	25%	$4,508,089	$2,694,376	$2,424,565	$0	$4,165,427	$13,792,457	$0	$3,630,000	$10,162,457	$7,113,720
2014	50%	$9,016,178	$5,388,752	$4,849,130	$0	$8,330,855	$27,584,914	$0	$3,960,000	$23,624,914	$16,537,440
2015	75%	$13,524,267	$8,083,128	$7,273,695	$0	$12,496,282	$41,377,372	$0	$4,290,000	$37,087,372	$25,961,160
2016	100%	$18,032,356	$10,777,503	$9,698,261	$4,000,926	$16,661,709	$59,170,755	$0	$4,620,000	$54,550,755	$38,185,528
2017	100%	$18,032,356	$10,777,503	$9,698,261	$8,001,852	$16,661,709	$63,171,680	$0	$1,320,000	$61,851,680	$43,296,176
2018	100%	$18,032,356	$10,777,503	$9,698,261	$12,002,777	$16,661,709	$67,172,606	$0	$1,320,000	$65,852,606	$46,096,824
2019	100%	$18,032,356	$10,777,503	$9,698,261	$16,003,703	$16,661,709	$71,173,532	$0	$1,320,000	$69,853,532	$48,897,472
2020	100%	$18,032,356	$10,777,503	$9,698,261	$16,003,703	$16,661,709	$71,173,532	$0	$1,320,000	$69,853,532	$48,897,472
2021	100%	$18,032,356	$10,777,503	$9,698,261	$16,003,703	$16,661,709	$71,173,532	$0	$1,320,000	$69,853,532	$48,897,472
2022	100%	$18,032,356	$10,777,503	$9,698,261	$16,003,703	$16,661,709	$71,173,532	$0	$1,320,000	$69,853,532	$48,897,472
2023	100%	$18,032,356	$10,777,503	$9,698,261	$16,003,703	$16,661,709	$71,173,532	$0	$1,320,000	$69,853,532	$48,897,472
2024	100%	$18,032,356	$10,777,503	$9,698,261	$16,003,703	$16,661,709	$71,173,532	$0	$1,320,000	$69,853,532	$48,897,472
2025	100%	$18,032,356	$10,777,503	$9,698,261	$16,003,703	$16,661,709	$71,173,532	$0	$1,320,000	$69,853,532	$48,897,472
2026	100%	$18,032,356	$10,777,503	$9,698,261	$16,003,703	$16,661,709	$71,173,532	$0	$1,320,000	$69,853,532	$48,897,472

NPV
$148,398,382

IRR
98%

Appendix B

Project Code: P.PSH.0324

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Evaluation of Low Field Nuclear Magnetic Resonance for on-line measurement of meat quality attributes

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Executive Summary

- This report details a study conducted collaboratively by AgResearch MIRINZ, Murdoch University and Magritek to test the performance of a prototype Nuclear Magnetic Resonance (NMR) instrument using a Halbach magnet to predict shear force and drip loss. Previous results suggested that the Halbach NMR instrument could predict shear force on a small number of samples. The present study was carried out over two trials involving a larger number of samples

- Loin samples from 148 lambs slaughtered on two different days (April and May 2008) were used to access pH 24 hour *post mortem*, meat tenderness and drip loss at 1 and 4 or 5 days *post mortem.* Samples were measured at 5°C, mimicking a processing environment where the NMR instrument would be used.

- NMR relaxation measurements were carried out daily from one to five days *post mortem*. The relaxation was significantly affected by ageing, especially T_{21} time constant which decreased over the ageing period. This result is in agreement with previous studies.

- In the experiment we faced additional instrumental variations not observed before. The probe output amplitude changed significantly during the trials and should be included as variable in future studies. This instability may have had significant effect on the development of correlations to meat quality attributes.

- The observed correlations between pH, drip and shear force with NMR relaxation measurements was low, but significant, varying between 0.30 and 0.35. These were not as strong as previous studies, presumably due to the instability of the Halbach NMR instrument.

Recommendations

- Further work with upgraded one-sided NMR instrument like the Magritek NMR MOLE is recommended to confirm the positive results observed in previous studies and to possibly improve the correlations.

DRAFT

Contents

Page

1. Introduction

On-line quality measurement systems have the potential to manage quality during processing and predict product performance in the market as well as providing robust data which can be fed back to farmers and used in decision support.

There is evidence that low field nuclear magnetic resonance (LF-NMR) relaxometry can measure changes in water compartments in lean tissue associated with rigor, water binding and cooking as well as fat levels (Pearce and Rosenvold 2007). This indicates the potential for LF-NMR to measure key meat quality attributes such as tenderness, juiciness and water holding capacity. However, to utilise the full potential of NMR to measure meat quality attributes – drip loss and shear force, it should be implemented as an on-line rapid, non-invasive and non-destructive measurement technique. Existing LF-NMR bench top units are not suited for on-line use in meat plants. However, the development of a new LF-NMR device (the MOLE) by NZ-company Magritek allows meat to be placed on top of the device and may enable on-line measurement.

In the past 2 years, researchers from Murdoch University and AgResearch have carried out significant discovery research as part of MWNZ and MLA's MQST program. Working alongside Magritek, the project team has assessed the ability of the MOLE to measure key meat quality attributes in lamb. In the first study the MOLE was affected by temperature fluctuations (North *et al.* 2007). In the second study, the Magritek Halbach NMR instrument (not open-topped but may have potential as a lab-based instrument) was able to predict lamb shear force in a small sample set and showed correlation with meat ageing (Reis *et al.* 2007).

To assess the potential for the Halbach NMR instrument to predict meat quality, the experiment reported in this work was aligned with the Australian Sheep CRC program. Each year for the length of the Sheep CRC funding period, ewes from diverse information nucleus sheep flocks across Australia will produce progeny by 100 merino, maternal and terminal sires chosen from across the industry. There is an extensive list of measurements to be obtained from progeny slaughtered as part of the information nucleus which can provide the ideal opportunity for the on-line technologies to be tested and validated for a variety of phenotypes. Samples are collected for several analyses including: shear force (days 1 and 5 *post mortem*), pH decline, ultimate pH. We believe NMR has the most potential to measure shear force, pH and drip loss; and therefore the Sheep CRC program is ideal for evaluation of the LF-NMR performance.

2. Aims

The aim of this study was to confirm the potential of the LF-NMR Halbach instrument to predict shear force, drip loss and pH, using a larger sample base over two ageing periods - 1 and 5 pays *post mortem*.

3. Methods

3.1 Animals

The lamb loins used were sourced from the slaughter of the progeny from the Sheep CRC Information Nucleus flocks at the University of New England, Armidale. The samples from the Australian sheep CRC information nucleus progeny slaughters showed broad variability in shear force and pH for the first day (24 hours *post mortem*), which is very important from modelling point of view, since it provides a natural range of variation for development of models.

The lambs were slaughtered either in April 2008 (Trial 1; n = 82) or May 2008 (Trial 2; n = 66).

The day after slaughter, the loin was removed from each carcass, cut into thirds and the middle section used for LF-NMR and drip loss measurements, while the two remaining pieces were allocated to shear force measurements.

3.2 Measurements

LF-NMR measurements

LF-NMR measurements were carried out with a prototype NMR instrument using a Halbach magnet developed and built by Magritek (Wellington, New Zealand).

The LF-NMR measurements were carried out using the Carr–Purcell–Meiboom–Gill (CPMG) sequence with settings for trial 1 and 2 described in **Table 1**.

Spin echo measurements were also performed for vegetable oil samples using a two pulse sequence with the inter-pulse delay adjusted to give an echo centred in the middle of the acquisition window, with both pulses having the same length. Similar settings used for CPMG were used for the Echo measurement as shown in **Table 1**.

Table 1 - Parameters for Carr–Purcell–Meiboom–Gill (CPMG) and spin echo pulse sequences.

	Trial 1	Trial 2
B1 frequency (MHz)	12.17	12.18
Repetition Time (ms)	1500	1500
90 Amplitude (db)	-19	-18
180 Amplitude (db)	-13	-12
Pulse length (μs)	10	10
Echo Time(μs)	200	200
Number of Echoes	3000	3000

Trial 1

Four sub-samples of approximately 1 x 1 x 4 cm^3 were excised from each LD sample, two were cut parallel (A & B) and two perpendicular (C & D) to the fibre direction and stored in plastic tubes, which were used for LF-NMR measurements (**Figure 1**).

The samples were measured in random order every day from day 1 to day 5 *post mortem*. Each of the four sub-samples was measured in duplicate and a vegetable oil sample was measured after each sample (e.g. every 4^{th} sub-sample measured in duplicate).

On day 1 *post mortem* the first 7 samples had equilibrated to room temperature as the samples were cut, put in the tubes and sat on the bench to be measured in the NMR. The remaining samples were placed in chiller (5°C) until NMR measurements. From day 2, all the samples were measured cold (stored at 5°C and removed from the chiller immediately prior to measurements).

Trial 2

Three sub-samples of approximately 1 x 1 x 4 cm^3 were excised from each LD sample. The sub-samples were cut parallel to the fibre direction and stored in plastic tubes, which were used for LF-NMR measurements (**Figure 1**).

The samples were measured in random order every day from day 1 to day 5 *post mortem* and were stored at 5°C. On day 1, the samples were stored in the chiller (5°C) for at least 20 minutes prior to NMR measurements. The samples were collected from the chiller in batches of, on average, 12 tubes (3 sub-samples from 4 samples). Each tube was measured twice, with a turn of 90° between each measurement (**Figure 1**). A vegetable oil sample was measured regularly between batches. One spin echo experiment was run for every oil sample to monitor the probe output amplitude. The room temperature was monitored regularly.

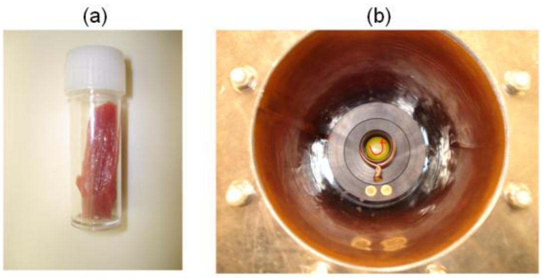

Figure 1.
Measurement tube with sub-sample (a) and Halbach probe with the sample indication the way sample is turned between replicates (b).

pH measurements: pH was measured 24 h *post mortem*. The pH and temperature measurements were taken in the left portion of the M. *longissimus thoracis et lumborum* (Loin or LL) using a pH-temperature data logger (WP-80, TPS Pty Ltd., Brisbane, Australia) with a glass body, spear-tipped probe (Mettler Toledo Order no. 10 406 3123), coupled with a temperature probe. The pH meter was calibrated before use, using buffers of pH 4 and pH 7 at room temperature.

Drip loss measurements: Drip loss was measured on a sub-sample using the centrifuge drip method (~0.3 g for each of three replicates) (Bertram *et al.* 2001). Drip loss was measured day 1 and day 4 *post mortem* for Trial 1 while for Trial 2 it was measured day 1 and day 5 *post mortem*.

Shear force measurements: Samples for shear force testing were cooked from frozen for 35 min in plastic bags at 70°C in an 80-L water bath before being tested using a Lloyd (Model LRX, Lloyd Instruments, Hampshire, UK) with a Warner-Bratzler shear blade fitted as described by Hopkins and Thompson (2001).

The MIRINZ tenderometer is similar to the better known Warner-Bratzler instrument but uses a different scale. The two scales are linearly related to each other (Graafhuis *et al.* 1991), where the shear force values measured with the Warner-Bratzler shear device are approximately 35% lower than values measured using a MIRINZ tenderometer (WBSF (kgF)= (0.63xMIRINZ KgF) +0.61)

3.3 Data analysis

The LF-NMR parameters were estimated with non-linear least square fitting for bi-exponential functions (Reis *et al.* 2007). Generalized Additive Model 'GAM' was used to relate LF-NMR parameters to meat quality attributes, *i.e.* y~f_1(y,b)+ f_2(x,b)+…, where f_i indicates a function for two covariates 'x' and 'b' (Reis *et al.* 2007). The software R[1] was used for data analysis.

To account for instrumental variation the GAM models were fitted independently by day and trial to avoid confounding with B_1 frequency, effects related to variation of probe output amplitude and ageing factor. As a result, the number of independent samples for fitting the models was reduced. The effects of temperature variation during the day were corrected, or at least minimized, with bivariate functions having B_1 frequency as one of the covariates. Any effects related to the variation of the probe output amplitude should also be corrected with an additional parameter (such as T_{21} estimated from oil samples), however there was not enough samples (*i.e.* degrees of freedom) to fit a model with such complexity.

4. Results

The mean values of relaxation time constant (T_2) and corresponding relative amplitude (K) for this study are shown in **Table 2**. The relaxation time constant T_{21}, lies in a similar range to the 2007 study, while the T_{22} values were found in a significantly lower range (Reis *et al.* 2007), which might be due to a difference in the sampling temperature between the two trials. In this study samples were stored at 5°C, whereas in the 2007 study the samples were stored at 20°C.

Table 2. Overall minimum, maximum, means as well as standard deviations[a] (STD) and standard deviation of residuals[b] (STD-Resid) of the LF-NMR parameters T_{21} (ms), T_{22} (ms), K_{21} (%) and K_{22} (%)

		T_{21}	K_{21}	T_{22}	K_{22}
Trial 1	Minimum	40.54	0.6	75.82	0.06
	Maximum	52.49	0.93	176.24	0.39
	Mean	47.07	0.83	113.74	0.16
	STD	1.84	0.04	13.86	0.04
	STD-Resid	1.07	0.03	7.68	0.02
Trial 2	Minimum	38.00	0.51	73.71	0.04
	Maximum	54.99	0.94	215.98	0.48
	Mean	46.62	0.82	112.08	0.17
	STD	2.65	0.07	21.11	0.07
	STD-Resid	0.81	0.02	6.92	0.02

[a] STD: Standard deviation of whole data set.
[b] STD-Resid: Standard deviation of residuals (difference between individual values of replicates and the corresponding mean of replicates).

Ageing effect

The changes in the relaxation time constants over the ageing period (described as days *post mortem*) are demonstrated in Figure 2. The most significant variation was observed in T_{21} for trial 2, with a similar decreasing trend observed in the 2007 study (Reis *et al.* 2007).

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[1] R Development Core Team (2007). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Drip loss

The mean, minimum and maximum as well as standard deviation values of drip loss are presented in **Table 3** together with the correlation between drip loss and LF-NMR parameters. The highest correlation was found for LF-NMR measurements carried out on day 1 in trial 2 with an R^2 of 0.3 with a range of 0.17-0.30.

pH

The mean, minimum and maximum as well as standard deviation values of pH are presented in

Table 4 together with the correlation between pH and LF-NMR parameters. The highest correlation was found for LF-NMR measurements carried out on trial 2 with an R^2 of 0.35.

Shear force

The shear force measured on day 1 and 5 in the two trials are shown in **Figure 3**. Further, the mean, minimum and maximum as well as standard deviation values of shear force are presented in Table 5 together with the correlation between pH and LF-NMR parameters. The highest correlation was found for LF-NMR measurements carried out on day 1 of both trials with R^2 of 0.31 with a range of 0.22-0.31, see also **Figure 4**.

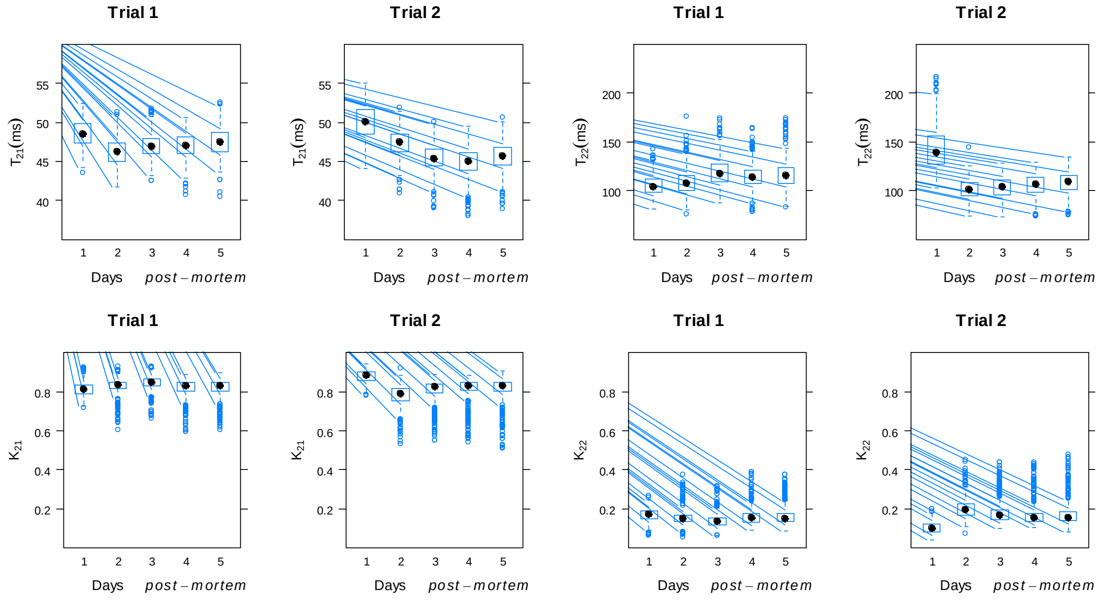

Figure 2.
NMR relaxation time constants and relative amplitudes as function of measurement day.

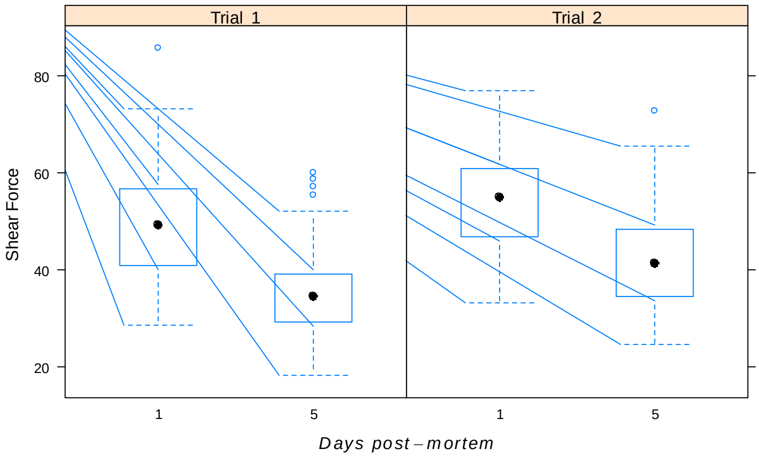

Figure 3
Shear force distribution for Trials 1 and 2.

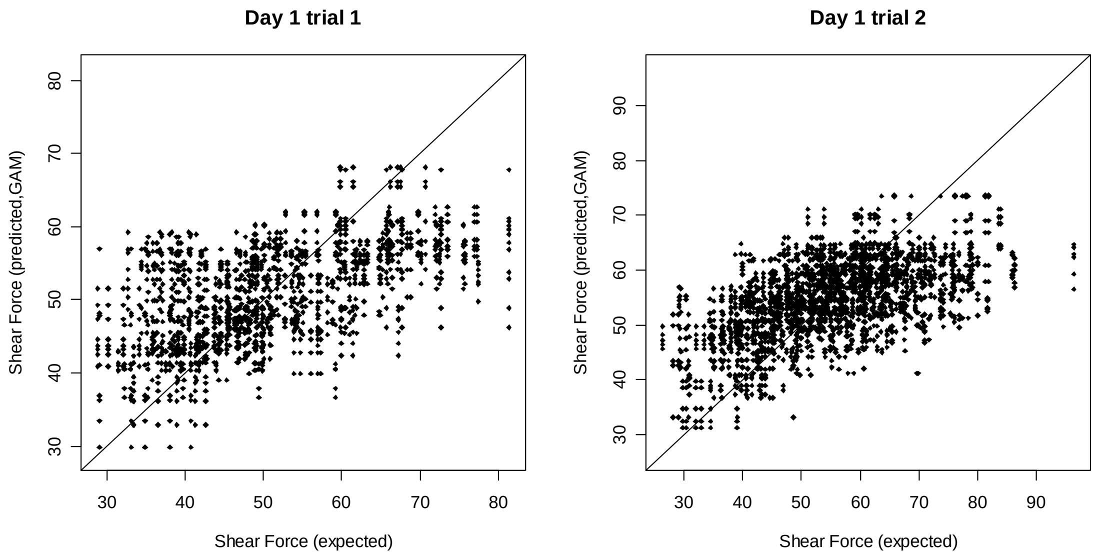

Figure 4.
Predictions of shear force for the first day of trial 1 and 2, by GAM (see Table 5 for further details).

Table 3: Minimum, maximum, means, standard deviations[a] (STD) and STD of the residuals[b] (STD-resid) of drip loss and the LF-NMR parameters T_{21} (ms), T_{22} (ms), K_{21} (%) and K_{22} (%) measured day 1 and day 4 *post mortem* (trial 1) and day 1 and day 5 (trial 2) as well as the correlations (R^2) between drip loss (%) and the LF-NMR parameters.

		Trial 1										**Trial 2**									
Days post mortem		1					4					1					5				
Number of samples		26					58					65					65				
		Drip	T21	T22	K21	K22	Drip	T21	T22	K21	K22	Drip	T21	T22	K21	K22	Drip	T21	T22	K21	K22
Minimum		0.8	43.58	81.38	0.72	0.07	0.4	40.76	78.46	0.60	0.09	0.6	44.54	103.24	0.78	0.05	0.7	38.91	75.31	0.51	0.08
Maximum		3.5	52.37	143.01	0.92	0.27	3.8	50.67	164.13	0.89	0.39	6.8	54.99	215.98	0.94	0.20	9.4	50.59	134.30	0.91	0.48
Mean		2.3	48.25	103.53	0.81	0.17	1. 7	46.93	114.16	0.82	0.16	3.0	49.97	143.34	0.88	0.11	3.0	45.56	107.10	0.81	0.18
STD		0.63	1.74	9.76	0.04	0.04	0.74	1.67	12.81	0.05	0.04	1.21	2.22	21.67	0.03	0.03	1.69	1.77	11.69	0.07	0.07
STD-Resid		1.25	1.04	6.89	0.02	0.02	0.70	1.09	7.44	0.03	0.03	1.32	0.88	11.84	0.02	0.02	1.14	0.81	4.95	0.03	0.03
GAM	R^2	0.17					0.2					0.3					0.28				
	DE[c]	19					23					37					33				
	Terms	f_1 (T_{22},B1) ***					f_1 (T_{22}, K_{22}):B1 **					f_1(T_{21},B1)***, f_2 (T_{22},B1) ** f_3(K_{22},B1) ***					f_1(T_{21},B1)***, f_2 (T_{22},B1) *** f_3(K_{22},B1) ***				

[a] STD: Standard deviation of data used in the model.
[b] STD-Resid: Standard deviation of residuals (difference between individual values of replicates and the corresponding mean of replicates) for data used in the model.
[c] DE - Deviance explained (%).
Statistical significance: '***' P ≤ 0.001; '**' P ≤ 0.01; '*' P ≤ 0.05 . DE - Deviance explained (%).

Table 4: Minimum, maximum, means and standard deviations[a] (STD) of pH and the LF-NMR parameters T_{21} (ms), T_{22} (ms), K_{21} (%) and K_{22} (%) measured day 1 *post mortem* as well as the correlations (R^2) between pH and the LF-NMR parameters.

		Trial 1					**Trial 2**				
Number of samples		30					66				
		pH	T21	T22	K21	K22	pH	T21	T22	K21	K22
Minimum		5.68	44.17	81.38	0.72	0.07	5.55	44.08	102.67	0.78	0.04
Maximum		6.10	52.37	143.01	0.92	0.27	5.98	54.99	215.98	0.94	0.20
Mean		5.83	48.68	105.65	0.81	0.17	5.71	49.93	143.30	0.88	0.10
STD		0.10	1.17	10.86	0.04	0.03	0.07	2.24	21.81	0.03	0.03
GAM	R2	0.25					0.35				
	DEb	30.8					40				
	Terms	f1(T21,B1)***, f2 (T22,B1)*					f1(T21,B1)***, f2 (T22,B1) *** f3(K22,B1) ***				

[a] STD: Standard deviation of data used in the model.
[b] DE Deviance explained (%)
Statistical significance: '***' P ≤ 0.001; '**' P ≤ 0.01; '*' P ≤ 0.05.

Table 5. Minimum, maximum, means, standard deviations[a] (STD) and STD of the residuals[b] (STD-resid) of shear force (SF in Kg) and the LF-NMR parameters T_{21} (ms), T_{22} (ms), K_{21} (%) and K_{22} (%) measured days 1 and 5 *post mortem* as well as the correlations (R^2) between shear force and the LF-NMR parameters

		Trial 1										**Trial 2**									
Days post mortem		1					5					1					5				
Number of samples		32					82					66					66				
		SF	T21	T22	K21	K22	SF	T21	T22	K21	K22	SF	T21	T22	K21	K22	SF	T21	T22	K21	K22
Minimum		28.8	43.58	81.38	0.72	0.07	15.1	40.54	83.14	0.61	0.09	26.4	44.08	102.67	0.78	0.04	16.6	38.91	75.31	0.51	0.08
Maximum		81.3	52.37	143.01	0.92	0.27	75.0	52.49	173.99	0.90	0.37	96.4	54.99	215.98	0.94	0.20	84.5	50.59	134.30	0.91	0.48
Mean		50.3	48.55	105.64	0.81	0.17	35.6	47.46	116.37	0.82	0.16	55.0	49.93	143.30	0.88	0.10	42.7	45.56	107.22	0.81	0.18
STD		12.1	1.77	10.84	0.04	0.03	10.8	1.7	13.25	0.05	0.04	12.6	2.24	21.78	0.03	0.03	12.0	1.76	11.65	0.07	0.07
STD-Resid		6.1	1.04	6.89	0.02	0.02	5.6	1.14	8.89	0.03	0.03	7.4	0.88	11.84	0.02	0.02	6.4	0.81	4.95	0.03	0.02
GAM	R2	0.31					0.22					0.31					0.26				
	Deviance explained (%)	33.2					23.2					32.9					27.4				
	Terms	f1(T21,B1)***, f2 (T22,B1) *** , f3(K21,B1) ***					f1(T21,B1) ***, f2(T22,B1) *** f3(K21,B1) ***, f4(K22,B1) ***					f1(T21,B1) ***, f2(T22,B1) *** f3(K21,B1) ***, f4(K22,B1) ***					f1(T21,B1) ***, f2(T22,B1) *** f3(K21,B1) ***, f4(K22,B1) ***				

[a] STD: Standard deviation of data used in the model.
[b] STD-Resid: Standard deviation of residuals (difference between individual values of replicates and the corresponding mean of replicates) for data used in the model.
Statistical significance:'***' $P \leq 0.001$; '**' $P \leq 0.01$; '*' $P \leq 0.05$'

5. Discussion

The aim of this study was to confirm the potential for the LF-NMR Halbach instrument to predict shear force, drip loss and pH, using a larger sample base over two ageing periods- 1 and 5 days *post mortem*. Starting with the best mechanical measure of tenderness, shear force, significant correlations against LF-NMR parameters were demonstrated with the highest correlation observed on day 1 of both trials with R^2 of 0.31 with a range of 0.22-0.31.

The correlations between NMR measurements and shear force were not as strong as those observed in the previous Halbach experiment (R^2 = 0.62; Reis et al. (2007), when the major challenge was the variability within muscle. Despite the larger sample number used and significant variation in shear force, which would help to overcome the within muscle variability, the R^2 was not improved in this experiment. Hence, the critical question of whether the LF-NMR Halbach instrument can estimate shear force could not be answered because instrumental variation not observed before took place during this study.

Two different versions of the Halbach prototype have been tested: one in the 2007 study; and the other in this study. The Halbach NMR instrument exhibits a fixed magnetic field B_0 and a second magnetic field B_1 produced by a Radio Frequency 'RF' pulse. B_0 is sensitive to temperature and thus so is B_1 frequency. The probe output amplitude is a measurement that indicates the quantity of the signal returning from the probe and consequently its sensitivity. During the trials a vegetable oil sample was used as a standard being measured regularly during the day. As shown in **Figure 5**, T_{21} varied with B_1 frequency throughout the day, the same is valid for the other LF-NMR parameters, and this variation is due to temperature fluctuations. Figure 5 also indicates that the dependence between T_{21} and B_1 frequency for the vegetable oil varied significantly between the measurement days; whereas in the 2007 study, the T_{21} and B_1 relationship was similar across all measurement days.

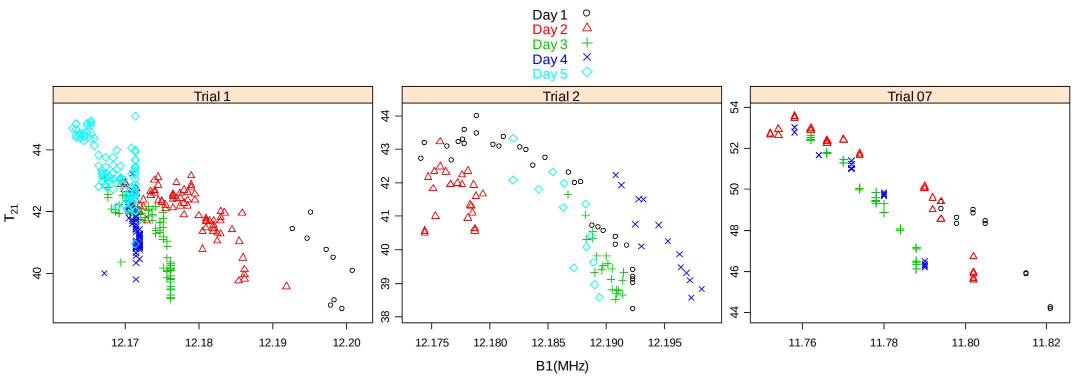

Figure 5.
Dependence between LF-NMR parameter (T_{21}) and B1 frequency for this study (trials 1 and 2) and the 2007 study for the vegetable oil sample.

These day to day variations were also observed in the probe output amplitude, as shown in **Table 6** and **Figure 6**.

Table 6. Measurements of probe output amplitude for oil samples trial 1 using spin echo sequence.

	Probe output amplitude (µV)
Day 1	340-320
Day 2	260
Day 3	250
Day 4	230-170
Day 5	200-140

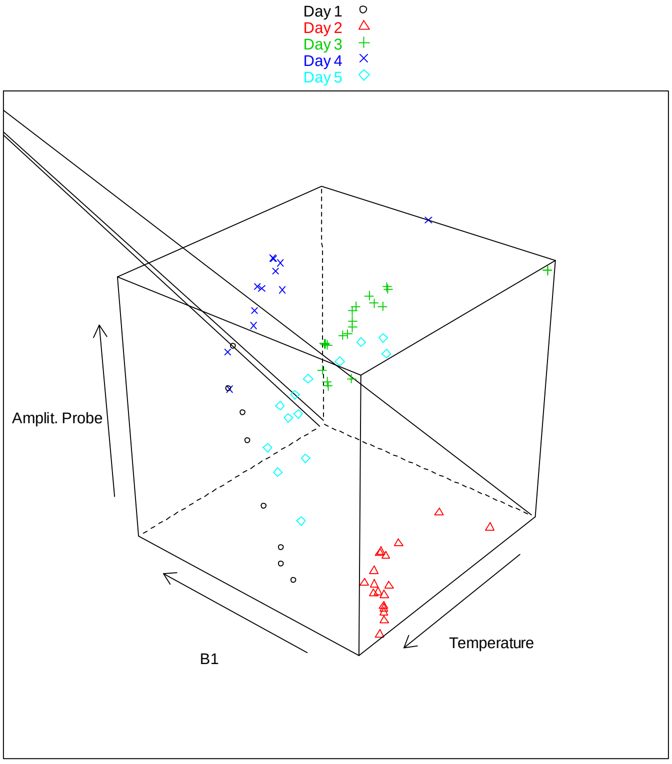

Figure 6.
Dependence between B1 frequency (MHz), probe output amplitude (µV) and temperature (°C) for trial 2.

The time required for the temperature of the room and the magnet (which produces B0) to reach equilibrium will also contribute to the day to day variation. For example, if the temperature of the magnet at the beginning of the day was different from any another day[2], even with the same room temperature, the time for the magnet equilibrate would be different. This characteristic of the magnet was not observed in the 2007 study,

[2] The room temperature was checked and set everyday before starting the measurements.

therefore it was not known before this study. The Halbach prototype used in 2007 was made primarily of plastic and the one used in this study was made of aluminium, which would explain the difference between the two studies. We observed a decrease in the probe output amplitude in trial 1 (Table 6) and replaced the amplifier for trial 2 in attempt to eliminate the variation in the output amplitude. It improved the level of the amplitude for the second trial. The result of the significant changes in probe output amplitude and B1 frequency during the trials are that trials 1 and 2 were carried out under varying instrumental conditions thus confounding the potential for proper correlations to be developed. B1 frequency was incorporated into the model for prediction of shear force to compensate the fluctuations during the day. This approach was successful for the 2007 trial, but not in the present study.

Further evidence of the negative impact of the instrumental variation was found by comparing the changes in time constants and populations over time observed between this study and the 2007 study. In the 2007 study, consistent changes in the time constants and populations over the ageing period were observed indicating that the analysis of ageing effect has shown the ability of NMR to detect changes in the *post mortem* muscle. In this study, the only consistent change over time was a decrease in T_{21} during ageing. Changes in T_{22}, K_{21} and K_{22} during ageing varied between the two trials. There were some factors that were different between trials such as the temperature of measurement but despite this the changes in water compartmentalisation are believed to still be consistent and thus similar results were expected.

The low R^2 over the ageing period is accentuated further because of the confounding effect between ageing time and reduction in shear force. In addition, we were unable to remove the within muscle variability, a similar problem in the 2007 study, by using the same sample for both NMR and shear force.

The correlations between drip loss and pH and LF-NMR measurements were stronger in trial 2 with R^2 values of 0.30 and 0.35 for drip loss and pH respectively. In the 2007 study the correlation with drip loss using the press drip method was higher (R^2 = 0.42). In this study, the relationship was expected to be higher due to the use of the centrifuge method. Again the inferior result may be due to instrument variation.

The T_{21} time constant demonstrated a significant decrease over the ageing period, particularly in trial 2. This effect is not related to instrumental variation. **Figure 5** shows that in trial 1 the average B_1 frequency for vegetable oil samples decreased from day 1 to 5, but in trial 2 and in the 2007 study this did not happen. This also suggests that replacing the amplifier between trial 1 and trial 2 decreased the instrumental variation observed in these last two trials.

Previous research suggested that the T_{21} time constant represents the intramyofibrillar water population essentially the immobilized water population with a T_{21} time constant of 30-50 ms with a T_{21} population of 80-95% and the T_{22} represents the extramyofibrillar or free water population with a T_{22} time constant of 100-250 ms and T_{22} population of 5-15% (Bertram & Andersen, 2004). As reviewed by Pearce & Rosenvold (2007) a decrease in T_{21} is due to an increased concentration of relaxation sinks, either due to a higher water concentration or because there is an increase in myofilament spacing, and this might be correlated with degradation of cytoskeletal proteins during ageing process (Kristensen and Purslow 2001). Thus the observation from Figure 2 is one more indication that changes in T_{21} are due to the ageing process. This observation is in agreement with our previous study (Reis *et al.* 2007).

6. Summary and conclusions

Measuring samples from the Sheep CRC trial gave an excellent opportunity for the assessment of the Halbach NMR system, since a broad natural variation in shear force was observed, and LF-NMR could be tested in a real environment as a tool for the selection of premium meat.

The critical question of whether the LF-NMR Halbach instrument can estimate shear force is still to be answered. We believe that the instrumental variation in the Halbach NMR instrument identified in this experiment has significantly affected our outcome.

The unexpected instrumental variation in this study will enhance the design of a system robust enough to work in the meat plant environment. The knowledge accumulated in this study will strengthen the development of the next stages of the project.

7. Future Implications and Research

As part of the plans for the current year of work, we will be testing the temperature-stabilised NMR MOLE instrument when it is available. The NMR-MOLE is expected to be available before the end of 2008 and validation will take place at AgResearch.

Upon confirmation that the NMR-MOLE works successfully, future plans include the development and evaluation of prediction equations for meat quality traits. And finally, the MOLE would then be customised for specific applications.

To account for the effect of Temperature on B1 frequency & probe output amplitude in future experiments it will be essential to:

- Measure the same sample at two different controlled temperatures (*e.g.* measure in the morning at 15^{o}C and afternoon at 20^{o}C). Or select a set of samples and measure them several times during the day.
- Perform several LF-NMR Wobble experiments in a standard material during the day to verify the probe tuning.
- Regularly measure the probe amplitude for a standard material throughout the experiment;

The implications for future studies using the open top probe (MOLE) will be that the temperature of the sample surface may need to be measured before and after the LF-NMR measurement.

8. Acknowledgements

The authors would like to acknowledge the valuable contribution and collaboration of Dr Geert Geesink from the University of New England, Armidale. Dr David Hopkins and Matt Kerr from DPI NSW also contributed greatly by conducting the shear force testing. Also essential to the project was the valuable assistance of Adam Stuart of AgResearch.

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