final report

Project code: A.SCT.0026

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Date submitted: February 2007

PUBLISHED BY
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Meat lean measurement using VE microwave instrument

Trials Performed at Keam Holdem Industrial Measurement Ltd, Auckland, NZ

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

Executive summary

The project goal was to progress development of an on-line, non-destructive, microwave frequency measurement system that can infer the CL (chemical lean) content of beef trim conveyed past a fixed sensing head.

The measurement system comprised a Keam Holdem microwave reflectometer attached to a portable table with conveyor belt. A single “microwave eye” was fitted in the table’s surface under the belt so it was looking upwards into the meat trims passing overhead. To calibrate and verify the system experimental work was performed in three separate stages to satisfy the following objectives.

- Determine best preparation practises for building calibrations;
- Determine the prediction accuracy for measuring beef trims and determine the effects for different trim stacking arrangements on accuracy;
- Find associations between the height of meat and the microwave prediction;
- Explore the use a non-linear calibration model to improve prediction accuracy;
- Document the microwave system’s ability to measure through a surface layer of fat.

Chemical lean predictions show the accuracy has significant dependence on the structural character and thickness of the beef trims. Visual inspection showed trims averaging 55 CL % to 85 CL% were found to have highly variable distributions of fat and lean material which adversely affected the prediction accuracy.

Predictions for different trim surfaces were also analysed, where top and base surface scans were found to increase in prediction divergence for trims in the 55 CL % to 85 CL % range. Scanning both surfaces typically improved the prediction accuracy twofold achieving a peak prediction error of between 2% and 5%.

Analysis of microwave predictions for different minced meat thicknesses has shown that predictions are affected by meat thickness, although the perturbances from thickness variations are systematic, an indication that future mathematical modelling may enable thickness compensation to be applied effectively.

Predictions for trims stacked in piles have shown it is possible to measure piles of multiple trims, however the density of the stacking arrangement influences the prediction. Best prediction accuracy requires a consistent trim stacking density. Division of trim surfaces into many small measurement areas has shown the prediction of CL at localised points to have good visual agreement with the surface and interior of the tested trim. This includes an ability of the microwave to observe internal fat deposits through surface layers of lean meat and vice-versa.

As it stands, the technique is not ready for use as a commercially viable chemical lean measurement system. However, Keam Holdem believes that it is possible to produce a commercial system based on the technique with further development work.

Contents

1 Introduction

1.1 Microwave Sensor

The microwave technique employed uses a beam of low-powered radio waves at microwave frequencies directed at one surface of the meat through an "aperture eye" such that a pattern of reflections is created and measured to infer compositional properties. A Keam Holdem reflectometer instrument was used to produce the beam of radio waves and collect the reflections. The reflectometer produced a stream of raw data to computer log files for latter analysis.

The previous microwave trial (SCT 022) had identified multiple reflections and the unknown yet variable meat sizing as factors limiting the prediction accuracy. Management of these issues was directed through the following design changes.

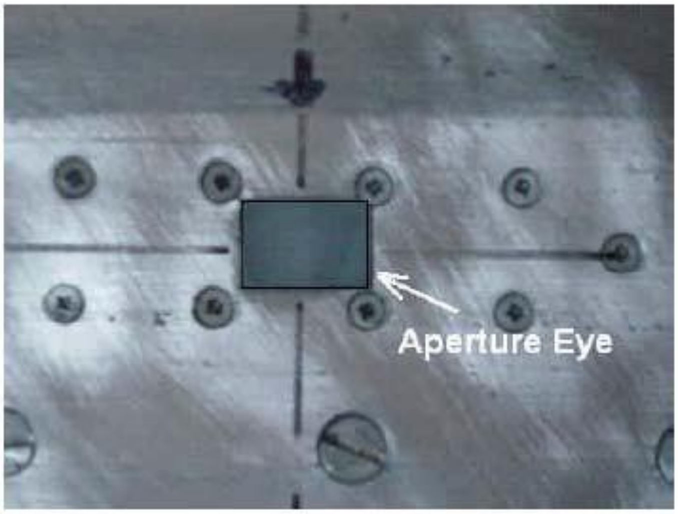
- Distance between the reflectometer and meat was regularised by conveying the meat using a motorised belt running in close contact above the aperture eye to maintain a constant clearance;
- The aperture eye was engineered to be as small as possible to minimise the number of measurements processed with the aperture not completely covered by meat or air (which happens whenever a peripheral edge of trim passes the aperture eye.) Three different designs for the aperture eye were constructed as prototypes and tested. The eye's purpose is to couple microwaves from the waveguide to the meat with control over the measurement geometry. The design needed to meet the following criteria.
- Limit measurement depth to approximately 40 mm to avoid measuring the above-meat airspace;
- Limit the horizontal measurement catchment to a minimum possible size;
- Effectively couple microwave energy to maximise the reflected wave sensitivities to CL variation.

Of the three prototypes, the iris, the tapered horn and the tuned tapered narrow wall aperture, the latter was found to best meet the design constraints. Testing of our prototype tuned tapered narrow wall aperture showed the measurement geometry was shaped approximately like a spherical ball with a diameter between 50 and 70 mm. We refer to each measurement of this spherical shaped space as an "elemental measurement" since many hundred such measurements were made on each trim to fully characterise trims of large size.

1.2 Conveyor Equipment

The conveyor belt was PTFE coated fibreglass mat, driven at speeds of 16 mm and 25mm per second in different experiments. Whilst stationary the belt could also be moved in fixed increments in directions sideways to the belt's normal direction of travel. A process of making sideways adjustments and driving the belt in both forward and reverse directions for successive passes of the meat allowed complete scanning of volumes of meat trim.

All measurements in these experiments were manually triggered, although it would be an easy extension to employ a form of automated triggering for an industry ready instrument. Photographs of the conveyor table and aperture eye are shown next page.



1. Aperture Eye. Size 22 x 15 mm.

2. Conveyor table. Belt was 180 mm wide.

1.3 Meat Samples

All meat was derived from beef trims. Meat was obtained both fresh from an abattoir in 27 kg cartons of trim and frozen in smaller quantities from a local butchery outlet. The abattoir cartons had been packed to 65% and 75% CL expectation, while the butchery trims were 75% to 90% and mince of 60% and 85% CL. Some selective re-sorting of the meat trims was used to create piles of trim that were fatter or leaner than the marked carton averages. It was noted that cartons of each particular CL grade had trims of consistent size and fat-lean distributions, probably resulting from the standardised carcass cuts used to prepare each specific CL grade.

1.4 Independent Reference Testing

With various meat samples being scanned over the microwave system, independent reference measurements of CL were needed for calibrating the system and to verify the predictive accuracy. Two methods were employed.

- Mince the meat samples after scanning and extract 20 g quantities from which the CL is inferred from moisture content determined by gravimetric drying. In this document we refer to this method as “mix-and-test”;
- Mix precisely weighed quantities of bulk fat and lean mince together to create new mince samples of intermediate CL grades. Only the CL of the original bulk minceneeds to be measured independently. We refer to this method as “mix-by-weight”;

The second method was found favourable for preparing calibration minces because it has less relative error between samples due to the precision of the weigh scales. The repeatability of our reference test was examined by testing samples in quadruplicate quantities. It was found that deviations within a group of four extracted 20 g samples was typically +/- 1% CL for leaner material, increasing to +/- 2% CL for higher fat samples.
Refer to the chart shown in Experiment 9 below.

2 Experiments and Results

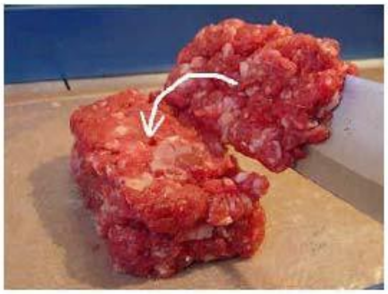
A complete list of the experiments and analysis performed during the trial is given in the following table.

3.0 Table – Experimental Schedule

Session	Exp	Description
October 2006	1	Examined size and height variation effects by measuring a sequentially constructed mince block.
	2	Further examine height variations by preparing and measuring mince samples of 3 different heights and 17 different CL grades using the mix-and-test reference method.
	3	Built a first calibration by analysis of the mince samples of 17 different CL grades from experiment 2.
	4	Applied a non-linear data model to extend the analysis of experiment 3.
December 2006	5	Built a calibration by preparing and measuring mince samples in 7 different CL grades using the mix-by-weight reference method.
	6	Verified predictions of trim CL by measuring 3 selected trims.
	7	Examined fat distribution in trim by separated testing of the inner region and peripheral regions of the meat trims of experiment 8#.
	8	Produced 2-dimensional CL images of the trims to extend the analysis of experiment 7# and examine the possible use of heuristic algorithms.
January 2006	9	Examined repeatability of our reference test by preparing mince samples in 10 different CL grades and reference testing in quadruplicate.
February 2006	10	Built a calibration by preparing and measuring mince samples in 5 different CL grades using the mix-by-weight reference method.
	11	Verified predictions of trim CL by measuring 5 piles of assorted trims.
	12	Examined prediction variations for different arrangements of trim pile stacking.

2.1 Size and Thickness Variations, Experiment 1

Method The experiment was conducted in two parts
i) Examine size variation by adding mince slices progressively around the mince block;
ii) Examine thickness variation effects by adding mince slices progressively to the top of the mince block.



3. **(left photo) Adding slices to increase area**
4. **(right photo) Adding slices to increase thickness**

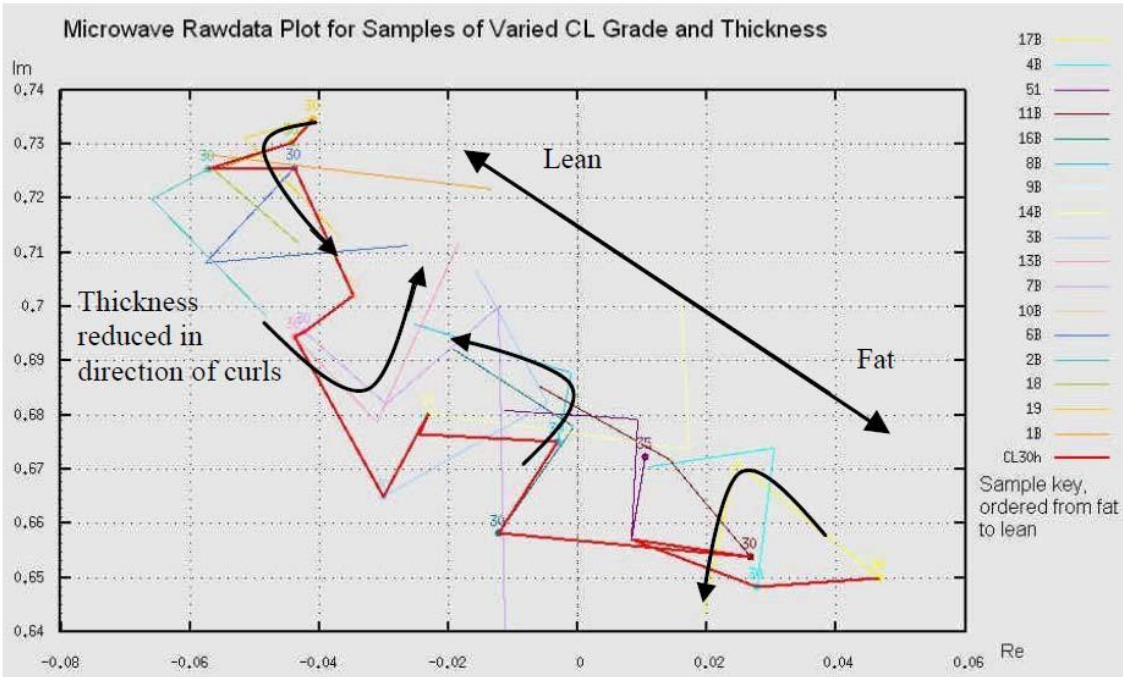
Result The microwave reflections responded to changes in the mince block size below 50 mm length and 70 mm width (where length is orientated along the natural direction of conveyor travel). The microwave reflections were less affected by thickness variations and the effect on reflection magnitude was approximately linear. Mince placed above 40 mm thickness had minimal effect. The elemental measurement space in the meat is therefore an asymmetric shape of 50 mm length, 70 mm width and 40 mm thickness.

2.2 Further Examination of Thickness Variations, Experiment 2

Method To further examine how thickness variations affect the microwave measurements of different CL grades, a set of 17 mince mixes were prepared using the mix-and-test reference method. Each mince sample was formed and scanned as blocks of 20, 25 and 30 mm thickness. See example mince block images below.

5. (left photo) Mince Block on Microwave Conveyor
6. (right photo) Example Mince Blocks of Varied CL Grades

Result Since all thicknesses examined were all inside the affected range found by experiment 1, each thickness variation produced a change in the microwave reflections measured. Changes were clearly systematic but follow a complicated pattern of loops as shown by the following raw data plot.



7. **Varied mince thickness causes a curling effect in the microwave reflections that takes a unique path for each different CL grade. The "Im" and "Re" quantities are due to the reflectometer capturing two reflection properties simultaneously for each measurement.**

The above pattern could be potentially exploited to help compensate for thickness variations, however due to the complexity of the pattern this would be nontrivial and we did not pursue this concept further. We recommend that specific signal processing / data analysis expertise be involved in any further development of the technology.

2.3 Built a First Calibration from 17 Mince Samples, Experiment 3

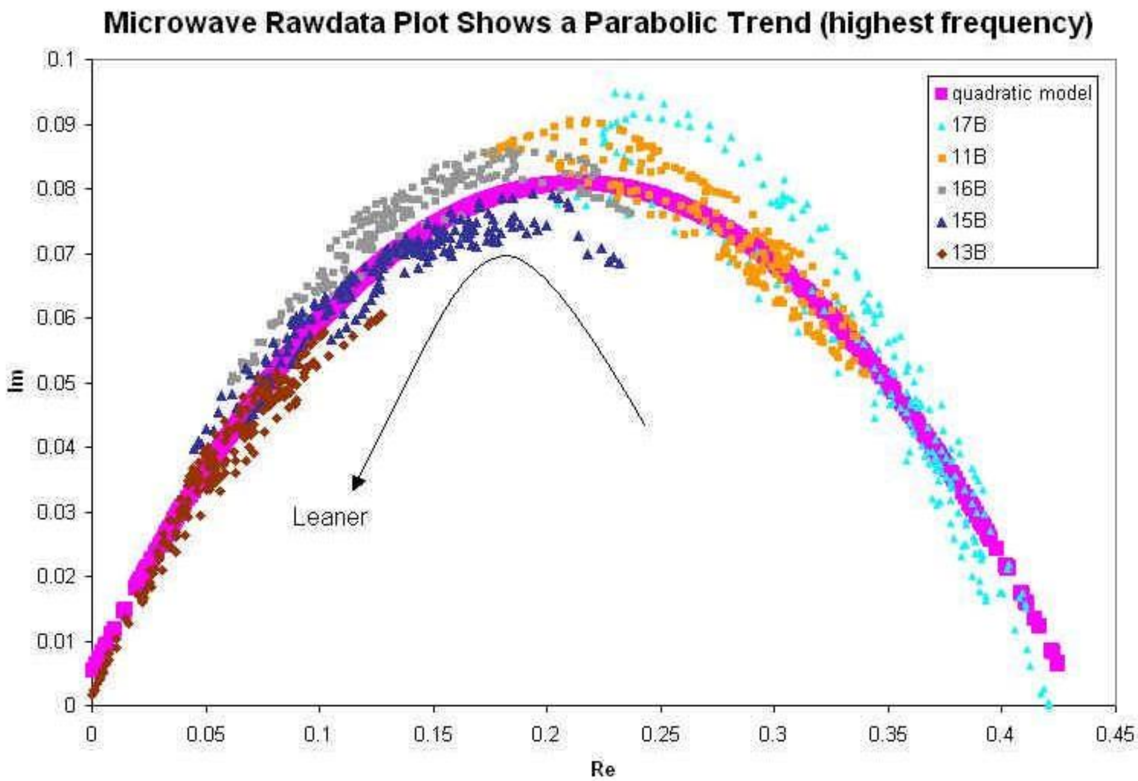
Method Data measured during experiment 2 was further analysed to find linear associations with the reference test results. Only the measurements of 30 mm thickness mince samples were analysed.

Result Chart plots of the raw data against the mix-and-test references produced a clear linear correlation but with significant scatter present (typically 4 to 6 CL%), implying either the microwave system was responding to CL variation in a non-linear manner or that the reference test contained significant error. We devised the alternative mix-by-weight reference test to minimise relative errors in the reference values during future experiments. No further analysis to find linear associations for the 17 mince grades was undertaken.

2.4 Apply a non- Linear Data Model, Experiment 4

Method Data measured during experiment 2 was again further analysed to find nonlinear associations with the reference test results. Only the measurements of 30 mm thickness mince samples were analysed.

Result On initial examination of the data we found that most of the reflection signals correlated linearly with the reference values (disregarding the scatter identified in experiment 3), so developing a non-linear data model would have been unnecessary. The highest microwave frequency was the exception, as the CL information it contained tended to follow a quadratic shape as shown by the following chart.



8. Distance along the model curve correlates with CL, whereas the distance at right angles was considered noise and not further utilised.

Shifting each measured point to it's nearest position on the quadratic model allows the CL of each point to be expressed as the distance along the quadratic model, requiring only a linear slope and offset adjustment to scale into actual CL units. We had expected the distance along the quadratic model to be a good predictor of CL but it was of no significant improvement compared with simply using the "Re" data as a predictor.

The quadratic model did not help to improve the prediction over a simpler linear model.

2.5 Build a calibration from 7 Mince Samples, Experiment 5

Method A set of 7 mince mixes was prepared using the mix-by-weight reference method. Each mince sample was formed and then microwave scanned as a block of 40 mm thickness.

Result The raw microwave reflection data correlated linearly with the reference values. Using all eight of the available scan frequencies the standard error of the correlation was

1.4 CL %, an improvement over experiment 3 where the mix-and-test reference method was used.

2.6 Verify Predictions of Trim CL, Experiment 6

Method A set of three trims was obtained from a local butchers outlet and were microwave scanned on both surfaces. All three trims contained significant regions of lean meat although the samples "102" and "103" also contained increasing larger regions of pure fat. All trims were of 35 mm and greater thicknesses. After completing the microwave scanning, reference values were obtained by mincing the trims and extracting 20 g samples for CL determination (using the microwave oven drying technique).

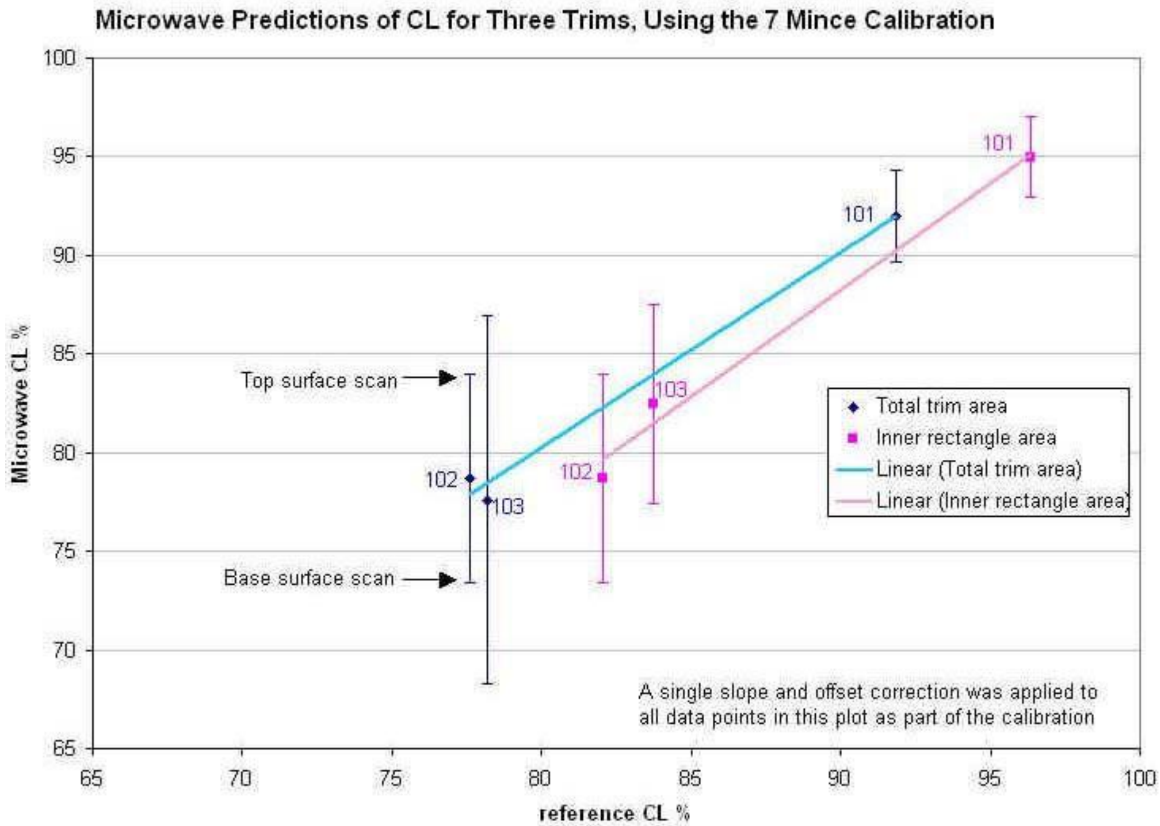
Result The 7 mince calibration from experiment 5 was applied to predict the CL of the trims using the data from microwave scans of both surfaces. The predictions were different for the two surfaces, with the prediction difference increasing for the samples that contained larger fat regions. The predictions and reference values are shown on a chart presented in experiment 7 below.

2.7 Examine Fat Distribution in Trim, Experiment 7

Method Each of the three trims used in experiment 6 were marked with surface paint to indicate an inner area. The inner area was separately microwave scanned and reference tested so predictions of the inner area could be compared with predictions for the whole of each trim.

9. Trim Inner Areas marked for separate analysis

Result The 7 mince calibration from experiment 5 was applied to predict the CL. The microwave predictions of CL and the reference tests both indicated that the inner areas were leaner than the total areas for all three trims. The chart below shows the predictions for both surfaces plotted against the reference CL values. The leaner inner areas probably resulted from the cut methods used to prepare the trim from carcass. On the carcass the lines of fat are obvious places to make the trim cuts so it is probable that more fat is distributed around the trim peripheries.



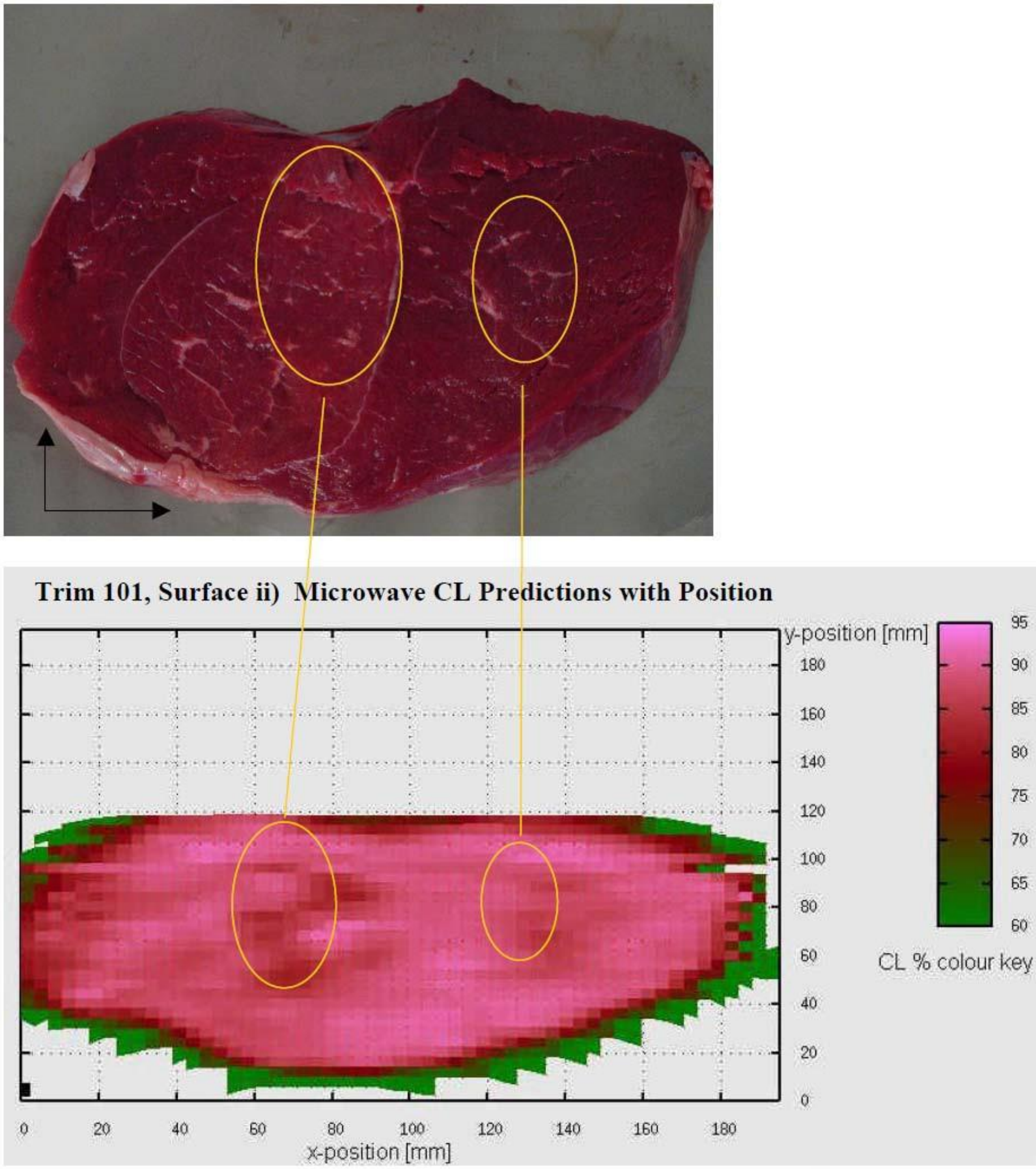
10. The Inner Area appeared consistently leaner, shown by the reference method and microwave predictions. The short horizontal bars at each point indicate the predictions made for each individual surface.

2.8 Produce 2-Dimensional Images of Trim CL, Experiment 8

Method The data from the three trims microwave scanned in experiment 7 was further analysed by applying the 7 mince calibration from experiment 6 and then arranging and plotting the data points on a 2-dimensional surface to show the CL prediction at every physical location. Separate plots were produced for each surface of each trim.

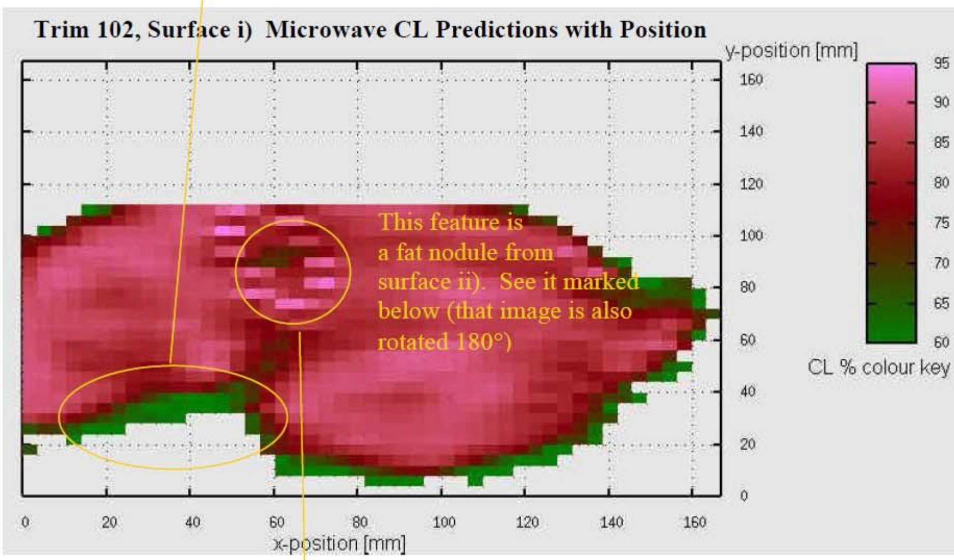
Result Several of the surface plots revealed special features and these are shown and explained with the images below.

2.8.1 Trim 101, Surface ii)



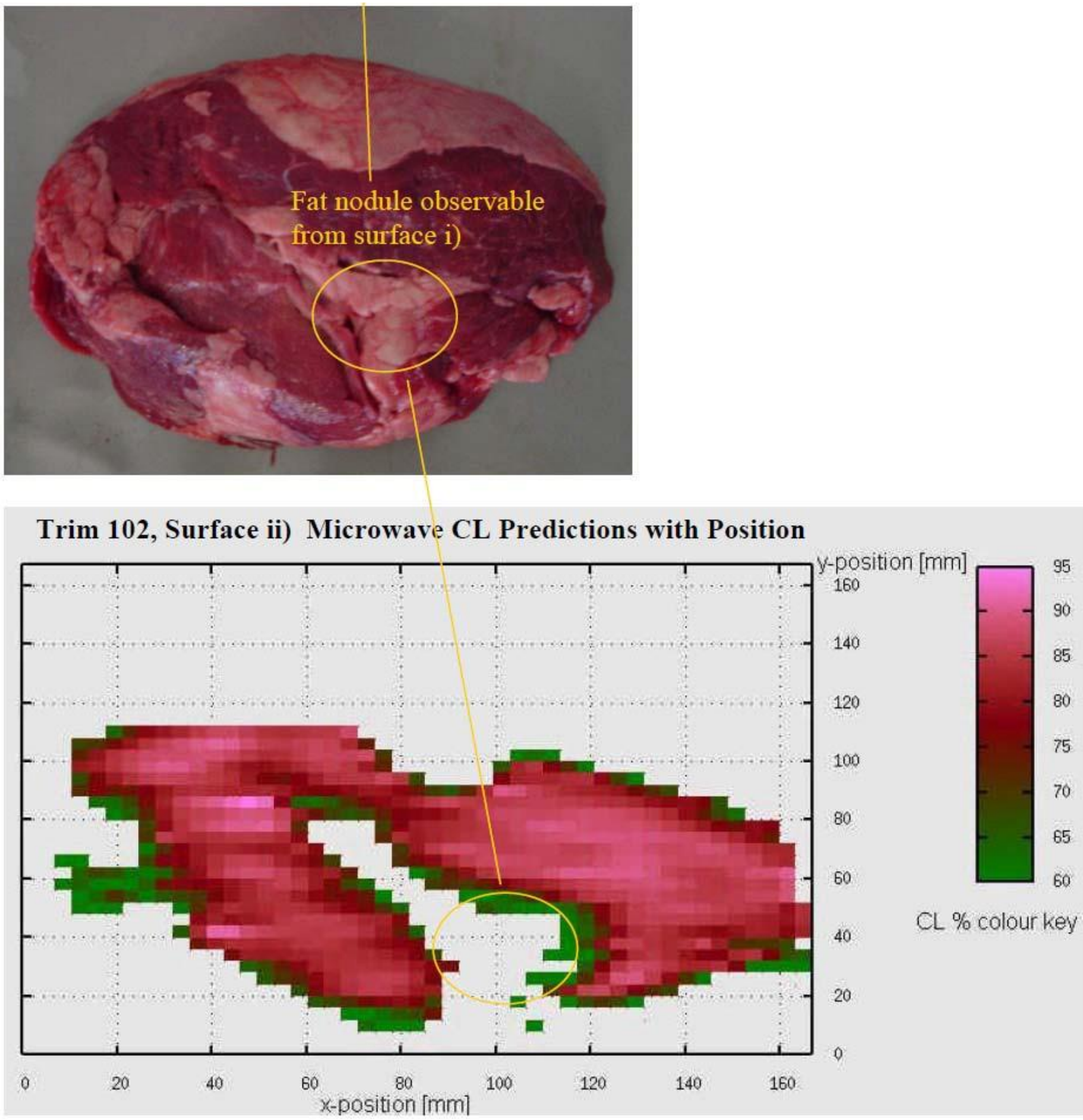
11. Colour rendering shows two fat regions. The peripheral area appears as fat in the microwave prediction.

2.8.2 Trim 102, Surface i)



12. Microwave prediction of fat content is approximately constant across the surface except for the region as indicated.

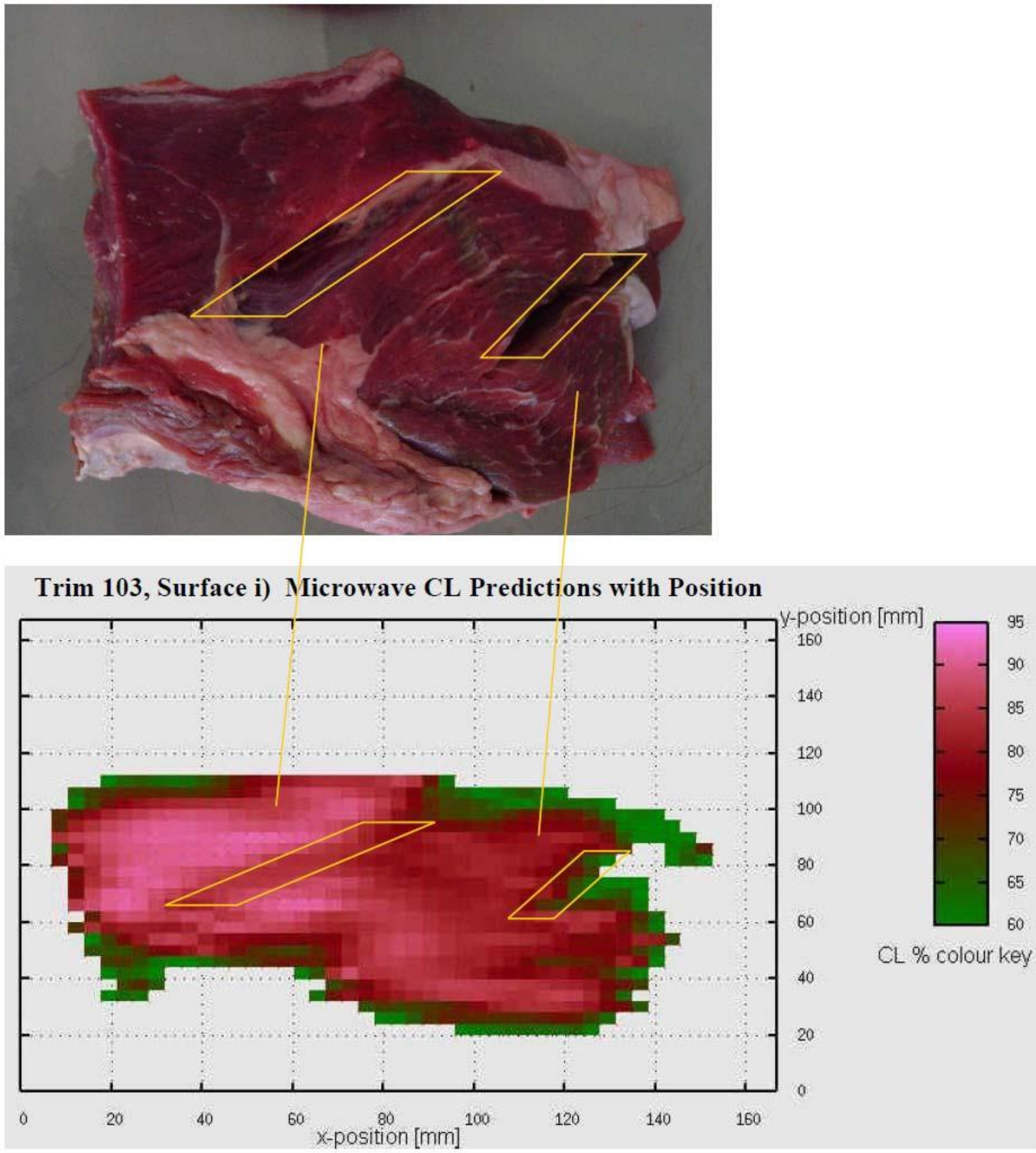
2.8.3 Trim 102, Surface ii)



13. The larger regions of fat in this trim show the localized microwave predictions of CL have good visual agreement with the trim photograph above.

The image of microwave predictions for trim 102, surface ii, shows that larger regions of pure fat do not register as part of the meat area. All the above measured points need to be combined to form a single CL value representing the whole surface, a process that may be enhanced by assuming the points measuring as non-meat that are flanked by meat are in fact fat regions that need to be included in the final CL value.

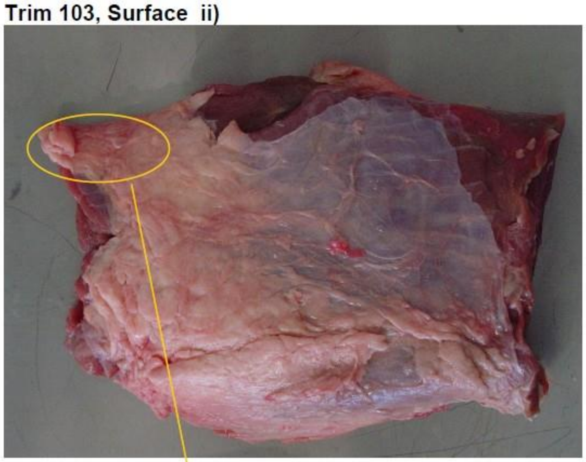
2.8.4 Trim 103, surface i)

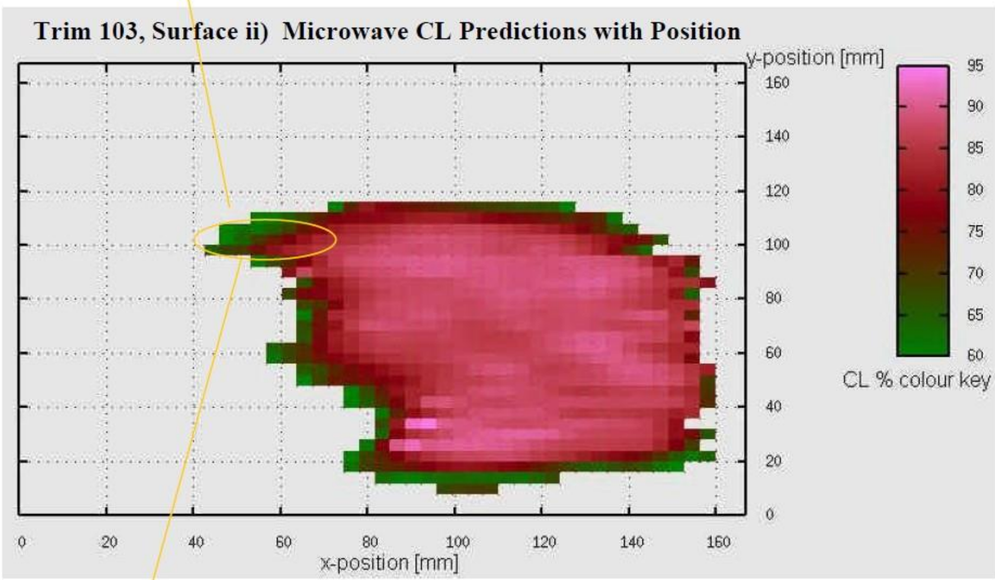


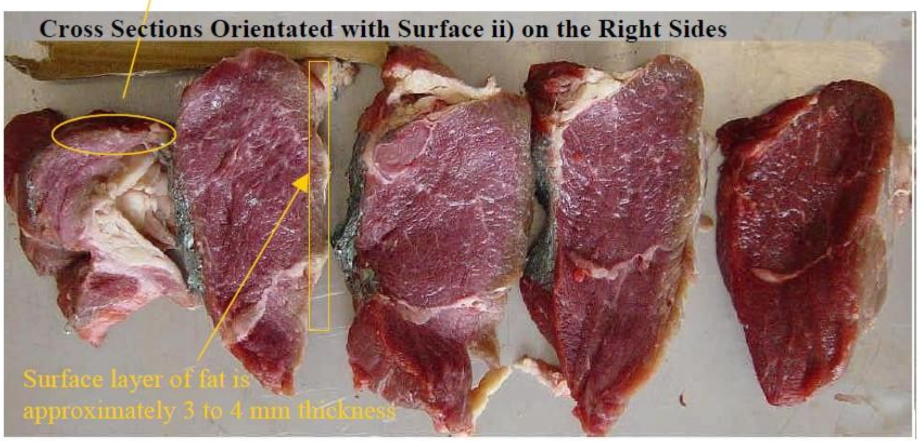
14. Air gaps in the trim bias the prediction towards fat

The image of microwave predictions for trim 103, surface i, shows that cracks or air gaps in the trim appear as areas of higher fat content. This effect may be due to a combination of the microwave interaction with the air voids and due to additional fat being present in those areas being the original cause for cracks to have developed.

Trim 103, Surface ii)





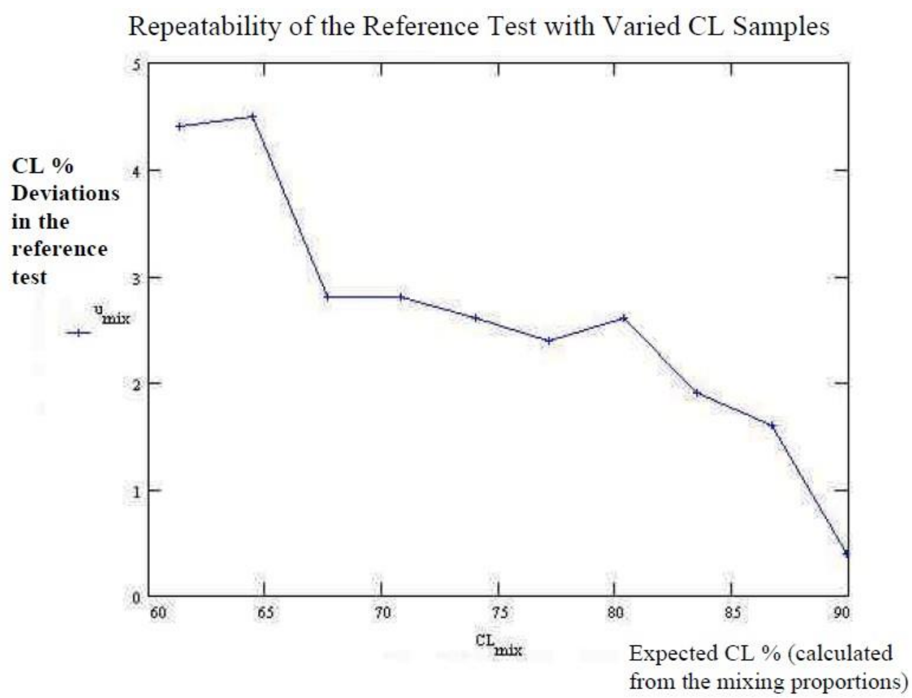


15. **Microwave prediction successfully observed the lean bulk of trim material through a surface layer of fat.**

2.9 Examine Repeatability of Reference Test, Experiment 9

Method Two CL grades of mince were purchased from a local butchery outlet and mixed in precise proportions to create ten different CL grade samples. Smaller 20 g samples were then extracted in triplicate from each of the ten CL grades and tested for CL content using a slow oven drying method.

Result The deviation in each group of three extracted samples was closely related to the average CL of the group. The deviations include errors from the drying process and variations in the extracted samples (caused by localised variations of CL through the original ten CL grade samples.) A chart plotting the deviation in each group of three extracted samples with the expected CL of the groups is shown below



16. **The extraction and reference testing of samples appears to become less repeatable as the average CL of the sample decreases.**

2.10 Build a calibration from 5 Mince Samples, Experiment 10

Method A set of 5 mince mixes was prepared using the mix-by-weight reference method. Each mince sample was formed and then microwave scanned as a block of 40 mm thickness.

Result The raw microwave reflection data correlated linearly with the reference values. Using two of the eight available scan frequencies the standard error of the correlation was 6.3 CL %. This is more scattered than the calibration fit of experiment 5 due, possibly due to the reduced number of mince mixes used to prepare this calibration.

2.11 Verify Predictions of CL for Trim Piles, Experiment 11

Method A set of five trim piles was prepared from selected fresh meat (slaughtered previous day). Piles 1, 2 and 3 were packed for an expected 60 to 70 CL %. Pile 4 was packed for 85 CL %. Pile 5 was packed for 40 CL %. The actual CL grade of each pile was reference tested and is presented with the results below. After preparation, each trim pile was immediately wrapped in plastic to prevent moisture loss. Piles 1 and 2 contained large regions of localised lean and fat material. Pile 3 contained a layer of surface fat across one complete surface. All piles were of 35 mm and greater thickness, except pile 3 where approximately one-quarter of the volume was between 10 and 30 mm thickness. Each pile was microwave scanned on both surfaces. Photographs of the piles are shown below.

After completing the microwave scanning, reference values were obtained by mincing the trims and extracting 20 g samples for CL determination (using the microwave oven drying technique).

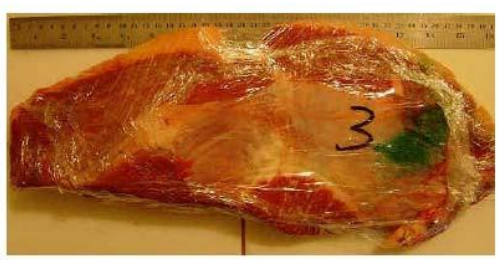
17. Pile 1, base surface 420 mm x 190 mm

Pile 1, top surface

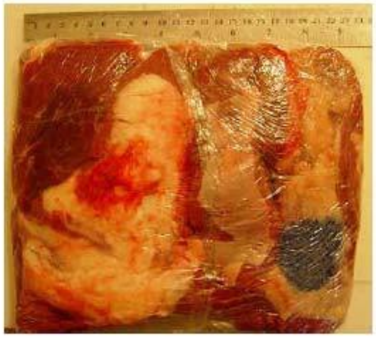
18. Pile 2, base surface 370 mm x 190 mm

Pile 2, top surface

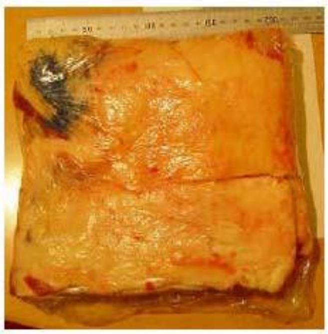
19. Pile 3, base surface 335 mm x 165 mm



Pile 3, top surface

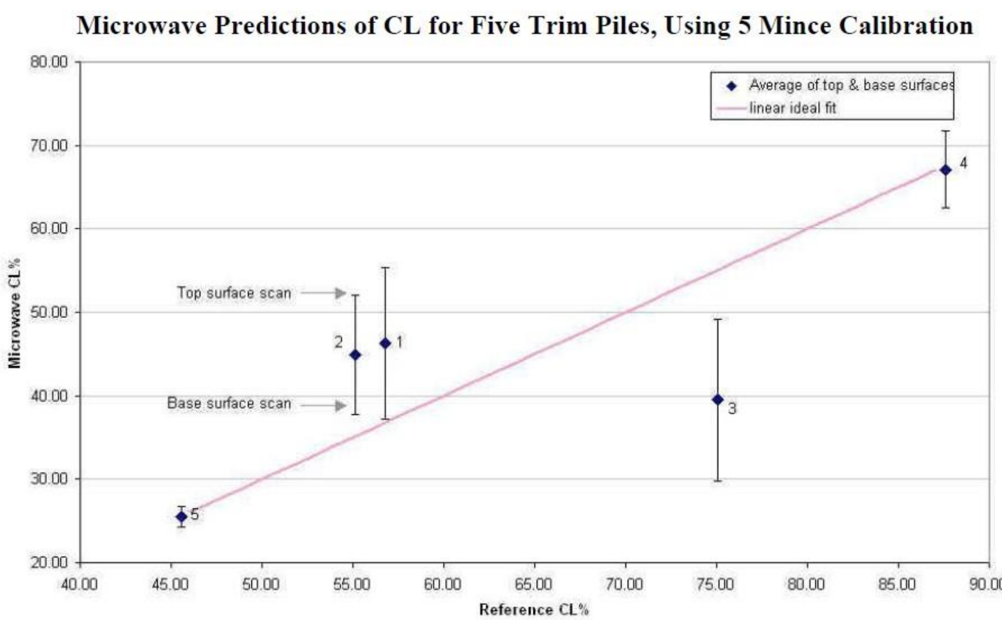


20. Pile 4, base surface 230 mm x 180 mm   Pile 4, top surface



21. Pile 5, base surface 200 mm x 185 mm   Pile 5, top surface

Result The 5 mince calibration from experiment 10 was applied to predict the CL of the trim piles using the data from microwave scans of both surfaces. Predictions and the reference values are shown on the chart below.



Trim pile 3 was of reduced thickness compared with the other trims used in the experiment. Reduced thickness is the most probable cause of trim 3 having an under-predicted CL value.

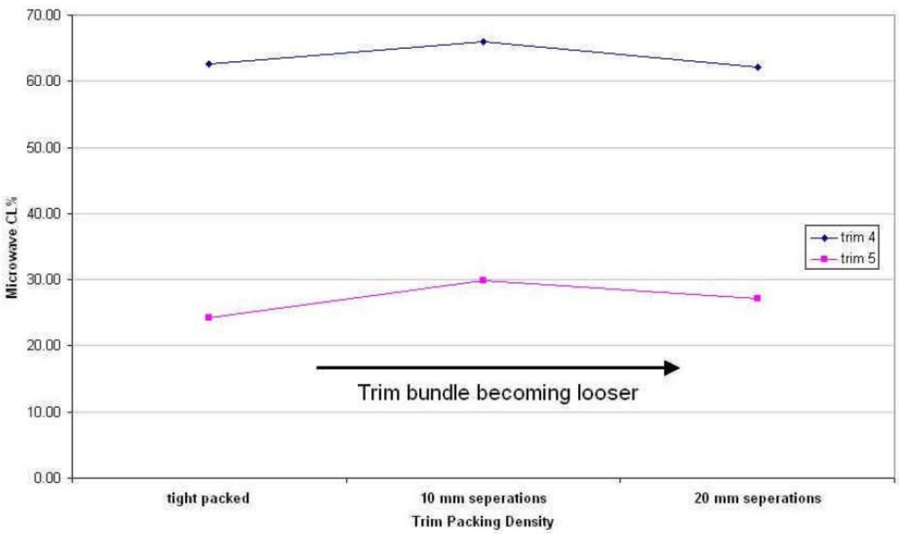
2.12 Examine Prediction Variations with Trim Pile Stacking, Experiment 12

Method Trim piles 4 and 5 of experiment 11 were reused to examine the effects of different trim stacking arrangements had on the prediction accuracy. Three different stacking arrangements were measured for each trim pile, starting with tight packed piles (high density) and finishing with looser piles of 20 mm gaps between adjacent trims. The white lines on the following photograph show an example of the gaps introduced.

22. **Gaps (marked white lines) were introduced by separation of the trims. The pile was scanned with three different levels of trim separation. This photo is of the most extreme separation of trim 4.**

Result The introduction of gaps between the trim pieces was found to influence the prediction of CL. The predictions for both the lean trim pile (pile 4) and high fat pile (pile 5) were similarly affected by offsetting the CL prediction by an amount dependent on the size of the gaps. The chart below shows this effect. Increasing the gaps larger then 20 mm separations would likely lead to a more fat biased prediction.

Influence of Trim Pile Packing Density on the Microwave CL Prediction



23. **Introduction of gaps between trims in a pile influence the microwave CL prediction. The influence appears similar for significantly different CL grades.**

3 Suggested Path to Commercialisation

As it stands, the technique is not ready for use as a commercially viable chemical lean measurement system. However, Keam Holdem believes that it is possible to produce a commercial system based on the technique with further development work.
Issues currently identified as limiting the prediction accuracy can now be summarised as follows.

1) Inability of microwaves to identify areas of fat from areas of air;
2) Inconsistent predictions for varied fat-lean profiles through the trim;
3) No current compensation for different trim thicknesses;
4) No current mechanical solution for measuring both sides of trim simultaneously;
5) No current mechanical solution for stacking trims to a consistent stack density.

Issues 1 and 3 may be solved by the addition of a height sensor to profile the trim thickness across the whole width of the trim. Laser or camera technology may be used. Issue 2 may be solved through the use of microwave data at a greater number of frequencies to assist separating the fat-lean profile information from the remaining chemical lean and thickness information in the raw data. Solving Issues 4 and 5 will require mechanical design expertise to find handling solutions. Keam Holdem recommends that further development leading tocommercialisation be achieved by forming a group comprising suitable mechanical expertise, preferably by a company that already has experience producing equipment for the meat industry.