PRELIMINARY INVESTIGATION OF HIGH RESOLUTION IMPEDANCE SPECTROSCOPY FOR MEASURING SHEAR FORCE

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Abstract – Measurement of meat traits using prediction tools is a challenge for the meat industry as the associated technology must be robust, produce accurate and reliable predictions and be relatively easy to use. These requirements have seen many technologies fail. In this study preliminary consideration has been given to the application of impedance spectroscopy for predicting the tenderness of lamb. As it stands the technology improves on previous impedance studies by using 4 current electrodes and by undertaking 3 scans in very high resolution at each measurement time. The results suggest that differences in tenderness between samples are reflected by changes in impedance. Thus the technology could be used to screen meat into say tough and tender categories at 1 day post-mortem, but the ability to predict 5 day shear force from 1 day impedance measures was not totally consistent.

Key Words – lamb, impedance, tenderness

I. INTRODUCTION

The three factors that determine meat tenderness are "background toughness", the toughening phase and the tenderisation phase. The toughening and tenderisation phases take place during the post mortem storage, or ageing period [1]. It is now well-established that post mortem proteolysis of myofibrillar and associated proteins is responsible for tenderisation, but it is a matter of debate about which proteases are responsible for tenderisation and which muscle proteins are degraded [2,3]. Nevertheless as a consequence of this degradation of proteins the molecular structure of meat changes during ageing. Attempts to measure these changes and relate them to instrumental measures of tenderness have been extensive [4] and impedance is one of the technologies that have been studied.

Impedance is measured as the opposition to the flow of electricity. It has resistive and capacitive components when measured in biological tissues [4]. Previous work on impedance has shown that electrical impedance of meat decreases as ageing progresses and that, after *rigor mortis*, changes in membrane properties make impedance measures problematic [5]. These authors did however show that because meat displays anisotropic characteristics, if longitudinal and transversal measurements were made and an anisotropy index determined, this was strongly correlated to fibre strength in meat when measuring at a frequency of 100 Hz. Previous research on impedance for measurement of meat has been limited to systems using 2 electrodes and this has the potential for polarisation of the electrodes to impact on measurement. The 4 electrode approach used by INPHAZE Pty Ltd provides opportunity to avoid this issue. Linked to this the INPHAZE Pty Ltd high resolution EIS technology enables scanning across a range of frequencies and the ability to undertake repeated scans on the same sample [6]. Whether the alternative impedance spectroscope developed by INPHAZE has the resolution to give repeatable predictions of tenderness (measured as shear force), was the focus on the experimental work described in this paper.

II. MATERIALS AND METHODS

Samples of m. *longissimus* from the lumbar section of 6 lamb carcases (both sides of the carcase) were purchased from a butcher and all external fat removed. Each loin piece was approximately 250g. These samples were 1 day aged. Each sample was cut in half and trimmed to 65-70 g with dimensions of approximately 60-70mm length, 40-50mm width, 20-25mm thick.

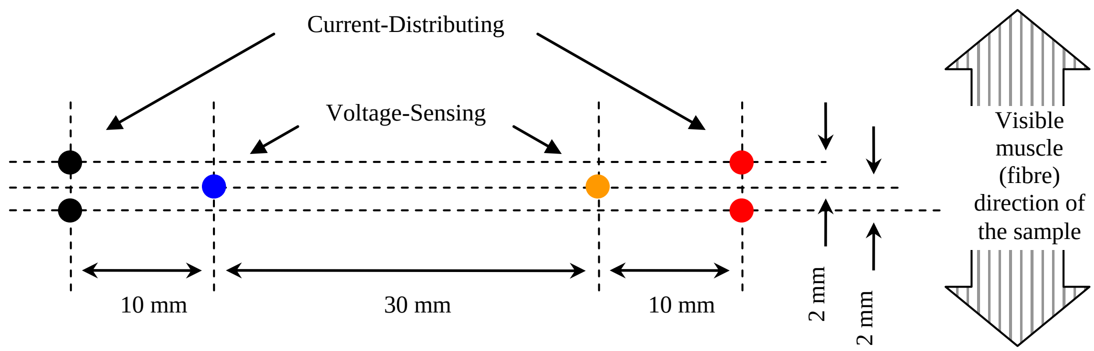

Figure 1. Schematic of the measurement protocol.

Samples were randomized by position (cranial and and caudal) to either ageing for 1 or 5 days. Samples aged for 1 day were measured for impedance and then frozen (-20° C) and the other half of the samples were also measured at 1 day of age and then vacuum packed and held chilled (4-5° C) and measured for impedance at days 3 and 5 and then the samples frozen. This allowed a comparison between samples aged for 1 and 5 days against impedance measures and the measurement at day 3 allowed the change in impedance measures with time to be captured. Every sample was dried with paper towel 3 min before measurement. Each measurement took just under 30 min which included the use of 4 electrodes (56 milliHz ~ 1 MHz, 3 spectra) then 2 electrodes (447 milliHz ~ 1 MHz, 3 spectra). Pure gold (99.99%+) electrodes, 0.8mm in diameter were used with the layout shown in Figure 1. Shear force samples were weighed prior to cooking (mean 64.5 g). These shear force samples were cooked for 35 min in plastic bags at 71°C in a 90 L water bath with a thermoregulator and a 2000 W heating element (Ratek Instruments, Boronia, Victoria, Australia) and measured using a Lloyd Texture analyser as previously described [7]. The cooking batch was made up to 20 samples using 8 non-experimental samples. Samples used for shear force determination were weighed pre and post cooking (mean 53.0 g) to measure the amount of cooking loss. After cooking the samples were cooled in running water and patted dry using paper towelling before weighing. Cooking loss percentage was calculated from the following formula;

Cooking loss (%) = 100 x (1 – cooked weight/fresh weight)

Regression analysis was used to examine the relationship between shear force and impedance (ohms) using the statistical package GenStat 13.2 [8].

III. RESULTS AND DISCUSSION

The shear force results (Table 1) indicate that the samples were tender compared to what may have been expected particularly for 1 day aged samples [9]. This created less range than ideal for developing relationships as it is preferable to cover the range seen commercially, however as shown in Table 1 there were differences between samples aged for 1 and 5 days in shear force as expected (on average 4.5 N) and this was reflected in differences in impedance also. In agreement with other studies impedance values were lower as shear force decreased which Damez *et al.* [5] suggested reflects a change in conductivity, due to the degradation of membranes. The impedance measures given in Table 1 are mean values over the frequency range scanned from 56 milliHz ~ 1 MHz based on the use of 4 electrodes. Previous studies have used 2 electrodes [e.g. 5] and in others the number was not specified [10], but the use of 4 electrodes should reduce artifacts from polarisation of the electrodes. There was no apparent relationship between cooking loss and impedance measures.

Table 1. Mean shear force (SF) in Newtons for each sample (aged for 1 or 5 days), cooking loss (CL; %; 1 and 5 days), percentage change in SF during ageing, impedance (Z) in ohms (at 1 and 5 days) and percentage change in impedance.

Carcase	SF (1 d)	SF (5 d)	% SF Change	CL (1 d)	CL (5 d)	Z (1 d)	Z (5 d)	% Z Change
A	28.8	20.2	-30	19.8	15.7	430	310	-28
B	24.5	16.1	-34	18.6	18.4	225	170	-24
C	21.6	27.5	+27	19.5	20.0	155	210	+36
D	30.3	23.4	-23	17.8	17.3	460	370	-20
E	25.6	27.6	+8	16.6	16.2	275	315	+15
F	29.3	18.0	-38	16.5	18.6	390	170	-56

In the current study for 2 carcases the shear force after 5 days of ageing was higher than at 1 day of ageing and impedance measures increased, whereas for the other 4 carcases as shear force declined with ageing so did impedance measures (Table 1). This outcome reflects the effect of positional influences within muscle on shear force [e.g. 11] and is why the position was rotated to ageing treatment across the 6 carcases. Sampling of more carcases would allow this factor to be accounted for in analysis. However the result does verify that changes in shear force will be reflected in impedance independent of ageing period which is a positive outcome.

A particular point of interest was to compare impedance measures taken at 1 day of ageing on samples against the shear force of those samples that were aged for 5 days. This indicates the potential to use the technology for prediction purposes. Impedance and shear force measures at 1 and 5 days of ageing are compared in Figure 2. Samples measured on day 1, frozen and tested for shear force (•) showed a strong linear relationship between impedance and shear force (R^2 = 0.97), but those aged for 5 days, tested, frozen and then measured for shear force (×) showed a poor relationship (R^2 = 0.23). This is in agreement with other studies that have shown a weakening correlation between impedance and shear force as ageing progresses [10]. Samples tested for impedance at 1 day of ageing and frozen after 5 days ageing for shear force testing showed a linear trend: as impedance values measured on day 1 increased the shear force of the samples at day 5 increased (▲), however 2 samples did not follow this trend with a resultant R^2 = 0.03.

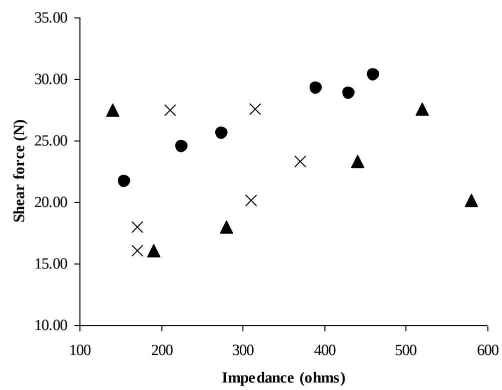

Figure 2. Samples were tested at 1 day and frozen (•), 5 days and frozen (×) and at 1 day, but frozen at 5 days (▲).

The pattern of impedance for changes in frequency (not shown) clearly shows that after 1 kHz there is a merging of impedance values between samples from the same carcase. This could be important for by restricting the frequency range, measurement time can be reduced, although measures at high frequencies are fast, whereas those at low frequencies take longer to complete. The general pattern of change in impedance across frequencies was similar during ageing, although the range in values decreased by 50% and this greater range for day 1 values explains why there is a stronger relationship with day 1 shear force measures.

Meat is electrically anisotropic, such that the electrical properties of meat are influenced by the direction of the electrical fields and for this reason Damez *et al.* [5] applied current to samples both longitudinally and transversally. This showed that measurements along meat fibres give lower impedance values than those taken across fibres (transversally) and this was attributed to the fact that current flowing across fibres must pass through cell membranes, whereas current flowing along fibres is mainly carried by ions in the extracellular space. In the current study measurements were performed across the fibres which should relate more strongly to changes in protein structure and thus tenderness, whereas it could be speculated that measurement along fibres would relate more strongly to changes in pH.

IV. CONCLUSION

Mean impedance values across the frequency range did show an association with shear force so that as shear force decreased, impedance also decreased and vice versa. However indications are that to develop prediction models for the technology further research is required based on a much larger sample so that the sources of variation can be taken into account and so the robustness of models can be tested.

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