Rigor Temperature and Functional Properties of Electrically Stimulated Beef

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Introduction

New Zealand produces a large volume of manufacturing meat, some of which is hot boned and frozen for export. For plants using electrical stimulation, the boxed hot-boned meat could enter rigor at a higher temperature than if stimulation is not used. This study investigated the effect of rigor temperature and frozen storage on electrically stimulated beef.

Materials and Methods

Heifers were captive bolt stunned and processed, with no electrical immobilisation or stimulation. The carcasses were high voltage electrically stimulated (a.c., 15 pulses/sec, 1130 V peak, 120 sec). The *semitendinosus* was removed approximately 45 min after slaughter and immediately sliced across the fibres into 10-mm thick cuts. Two cuts were weighed, sealed separately in a vacuum bag without vacuum and submerged in water baths maintained at 0, 5, 10, 25 and 35°C. After 24 h, the drip from each slice was determined. One slice from each treatment was used for pH, protein solubility, colour, cook loss and NMR T1 determinations (24-h time). The second slice was sealed (non vacuum) in a polythene bag, kept at -20°C for 1 month, then thawed for 14 h at 10°C and tested in the same way as the 24-h slices.

Meat pH was determined at room temperature by inserting an Ingold spear electrode directly into the samples at two different locations.

Weight loss from the fresh meat slices during 24 h holding (drip loss) and from frozen meat slices during thawing (thaw drip loss) was expressed as percentage of weight before slices were immersed in the water bath and before freezing respectively. Total moisture loss for each treatment was determine as % drip + % thaw drip + % cook loss (raw meat weight - weight after cooking/raw meat weight) of frozen samples.

Colour was measured using a Hunter Lab Miniscan. A 10-mm thick x 40-mm wide x 80-mm long slice of meat from each treatment was placed on a white polystyrene tray, overwrapped with high clarity d-film (stated oxygen permeability >2000 ml m^{-2} atm^{-1} 24 h^{-1} at 25°C) and kept in the dark for 4 h at 3°C to ensure complete bloom. Hue angle was calculated as $\tan^{-1}$ (b^*/a^*).

Protein solubility was measured as described in Farouk and Swan (1997).

NMR relaxation times (T1) of meat water were measured on a Bruker AC-200 NMR spectrometer at 200 MHz using an MAS probe. Samples were packed in 7-mm ZrO_2 rotors and spun at 500 Hz. The spin-lattice relaxation (T1) was measured using an inversion recovery sequence (RD - 180 - tau - 90 - FID). A recovery delay of 8 sec was used with variable delay times of 0.01, 0.05, 0.1, 0.5, 1, 5, 10, 20 and 40 sec.

A split plot design was used, with stimulation as the main plot and rigor temperature as the subplot. The experiment was replicated four times, each on a different day.

RESULTS AND DISCUSSION

Frozen storage had no effect on pH, so the pH values were averaged. Muscles held at 10 and 25°C had lower (P<0.001) ultimate pH values than muscles held at 0, 5 and 35°C (Table 1), whose ultimate pH were similar. The higher ultimate pH at rigor temperatures greater or lower than 10 to 25°C may be due to the early completion of glycolytic changes at these temperatures (Jeacocke, 1977).

Drip and total moisture loss tended to increase (P<0.001) with increasing rigor temperature (Table 1). Higher rigor temperature reduces protein functionality and increased isometric tension which may help explain why drip and total moisture loss tends to increase with increasing temperature (Penny, 1977; Devine *et al.*, 1996).

Change in L^* values in fresh (24 h) samples was not significant between 0 and 25°C (Table 2). In frozen samples, L^* values tended to increase with increasing rigor temperature. The fresh and frozen samples that had been held at 35°C were significantly lighter than samples held at other rigor temperatures. Protein denaturation and/or shrinkage of myofibrils at higher rigor temperatures may have increased light scattering and caused the higher Hunter L^* values at 35°C (Offer *et al.*, 1989). Muscles held at the lower rigor temperatures (0 to 10°C) had lower drip and total moisture losses, indicating they had a higher water holding capacity. These lower moisture losses may have resulted in less light scattering and made the meat appear more translucent and darker than muscles entering rigor at higher temperatures (Offer *et al.*, 1989). Frozen storage significantly reduced (P<0.05) the Hunter L^* value of samples except those kept at 25°C, where lightness increased with frozen storage.

Hue angle of 24-h fresh samples decreased (indicating increased colour stability) with increasing rigor temperatures up to 25°C, then hue angle increased (Table 2). In frozen samples, however, hue angle increased with rigor temperature. The data indicate that the activity of the metmyoglobin reducing enzymes in fresh samples 24 h postmortem increased as rigor temperature increased. Because of this higher activity, the enzymes expended their capacity to reduce metmyoglobin earlier than the enzymes in muscle entering rigor at lower temperatures. This reduced capacity then became evident after 1 month of frozen storage. With prolonged storage time, enzyme activity may tend to decrease relative to its initial activity so metmyoglobin content will tend to increase.

Samples entering rigor at 35°C had a significantly (P<0.001) lower total soluble protein than samples entering rigor at the lower temperatures (Table 3). Between 0 and 25°C, rigor temperature did not (P>0.05) affect total soluble protein content. Samples that had entered rigor at 0 to 10°C and then were stored frozen had higher (P<0.05) total soluble protein levels than the corresponding fresh samples. Muscle protein proteolysis during frozen storage may have increased the total protein solubility.

Myofibrillar protein solubility increased (P<0.05) with rigor temperature up to 25°C and then decreased significantly at 35°C, and myofibrillar solubility was higher (P<0.05) after frozen storage for samples entering rigor at 0 to 25°C (Table 3). Sarcoplasmic protein solubility decreased (P<0.001) with increasing rigor temperature and frozen storage, indicating that sarcoplasmic proteins were more susceptible to denaturation at lower temperatures and short term frozen storage than myofibrillar proteins (Table 3).

T1 values tended to get shorter (P<0.05) with increasing rigor temperature (P<0.001), and were shorter in frozen meat samples than in fresh meat. The decrease in T1 values may be due to changes in protein as a result of denaturation or aggregation. This decrease in T1 also implies that water molecule mobility increased, because the amount of free water increased with an increase in rigor temperature.

Data in the present study indicate that other than when muscle goes into rigor at around 35°C, sarcoplasmic proteins appear to be the major determinant of functional properties of both fresh meat and meat stored frozen for a short period. The role of sarcoplasmic proteins in functional properties of muscles entering rigor at lower rigor temperatures is further strengthened by the data on T1 relaxation times. T1 relaxation times and soluble sarcoplasmic proteins were positively correlated ($r = +0.87$, $P<0.05$); it is hypothesized that the adverse effect of high temperatures and of freezing and frozen storage on functional properties of meat begins with denaturation and aggregation of sarcoplasmic proteins before it extends to myofibrillar proteins. The high negative correlation between T1 and exudate losses ($r = -0.73$) and T1 and hue angle ($r = -0.7$) indicates that T1 values may be a good indicator of the state of muscle proteins, water binding and colour.

We conclude that within the current practices in New Zealand hot boning plants, damage to the functional properties of manufacturing meat that will undergo short term frozen storage can be minimized by rapidly chilling the muscles to 0 to 25°C; muscles that enter rigor at temperatures higher than 25°C may suffer adverse effects on water binding and other functional attributes.

References

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Table 1. Effect of rigor temperature and frozen storage on pH and moisture loss in high voltage stimulated beef

Rigor temperature (°C)	pH	24-h drip (%)	Thaw drip (%)	Total moisture loss (%)
0	5.57[a]	1.2[a]	7.7[a]	42.7[a]
5	5.54[a]	1.4[a]	7.8[a]	43.0[a]
10	5.47[b]	1.7[a]	8.6[b]	44.2[a]
25	5.48[b]	4.0[b]	8.6[b]	48.0[b]
35	5.54[a]	7.0[c]	5.8[c]	47.8[b]
LSD (5%)	0.04	0.74	0.74	1.7

a,b,c,d Values in columns sharing the same superscript are not significantly different ($P > 0.05$)
LSD = Least significant difference

Table 2. Effect of rigor temperature and frozen storage on colour and NMR T1 in high voltage stimulated beef

Rigor temperature (°C)	L* value		Hue angle (degrees)		NMR T1(msec)	
	Fresh	Frozen	Fresh	Frozen	Fresh	Frozen
0	42.3[ab]	39.5[a]	44.9[a]	45.7[a]	862.7[a]	681.7[a]
5	41.5[a]	38.5[a]	43.6[b]	43.9[b]	785.2[b]	642.2[a]
10	42.1[ab]	41.3[b]	43.0[b]	45.4[a]	723.2[c]	681.2[a]
25	43.0[b]	44.3[c]	40.9[c]	48.6[c]	838.7[ab]	643.5[a]
35	47.7[c]	45.8[d]	44.8[d]	50.2[a]	681.2[c]	585.0[b]
LSD (5%)	1.2	1.2	1.3	1.3	56.8	56.8

Fresh = 24 h samples; Frozen = samples frozen for 1 month; Other abbreviations are described in Table 1.

Table 3. Effect of rigor temperature and frozen storage on protein solubility (mg/g) in high voltage stimulated beef

Rigor temperature (°C)	Total solubility		Sarcoplasmic protein solubility		Myofibrillar protein solubility	
	Fresh	Frozen	Fresh	Frozen	Fresh	Frozen
0	172.3[a]	180.6[a]	72.7[a]	59.3[a]	99.6[a]	121.4[ab]
5	174.1[a]	185.3[a]	73.3[a]	67.7[b]	100.9[a]	117.5[a]
10	172.0[a]	190.1[a]	67.6[b]	64.0[b]	104.3[ab]	126.0[ab]
25	188.5[b]	188.9[a]	76.5[a]	56.9[a]	112.0[b]	131.9[b]
35	143.4[c]	128.8[b]	60.3[c]	54.9[a]	83.1[c]	73.9[c]
LSD (5%)	13.6	13.6	6.0	6.0	11.4	11.4

Fresh = 24 h samples; Frozen = samples frozen for 1 month; Other abbreviations are described in Table 1.