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An assessment of the effect of pulsed electrical fields on tenderness and selected quality attributes of post rigour beef muscle

Louise P. O'Dowd, Joshua M. Arimi, Francesco Noci, Denis A. Cronin, James G. Lyng *

Institute of Food and Health, UCD Dublin, Belfield, Dublin 4, Ireland

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ABSTRACT

The effect of conventional and PEF treatment (electric field strength: 1.1–2.8 kV cm^{-1}; energy density: 12.7–226 kJ/kg), frequency (5–200 Hz) and pulse number (152–300) on selected quality attributes of beef *Semitendinosus* (ST) was investigated. While PEF is viewed as a "non-thermal" treatment, it can induce moderate temperature rises (ΔT). To eliminate any potential effect of mild temperature increases, PEF treated samples were compared to conventionally treated (water bath) samples exposed to similar temperature rises (5–35 °C) and handling conditions. Weight loss, conductivity, water holding properties and particle sizes were measured pre- and post-treatment. PEF treatment that induced a ΔT of 22 °C significantly ($P<0.05$) affected weight loss of samples post treatment. Particle size analysis of the extracted myofibrils showed PEF significantly ($P<0.05$) affected the myofibrils while weight loss results suggest that PEF treatment may have led to slight changes in the cell membrane leading to more water loss. However, instrumental texture was unaffected by the treatments applied.

1. Introduction

Interest in pulsed electric fields (PEF) as a minimal food processing technology has increased in recent years with substantial advancement being made in the processing of liquid foods such as milk and juices (Grimi, Mamouni, Lebovka, Vorobiev, & Vaxelaire, 2011; Guerrero-Beltrán, Sepulveda, Góngora-Nieto, Swanson, & Barbosa-Cánovas, 2010; Noci et al., 2008). However, there is very little in literature on the use of PEF processing of solid foods and particularly muscle foods such as beef.

Operation of PEF involves inducing an electric field (kV cm^{-1}) on a food placed between two electrodes and energy is delivered into the food in the form of short wave pulses (Barbosa-Canovas & Sepulveda, 2005). While this effect has been studied for microbial inactivation if a similar effect could be induced in beef muscle it could alter muscle fibres and affect various quality attributes such as tenderness, water holding capacity and colour. Depending on the intensity of the field, changes in the cell membrane can occur, which can lead to the formation of temporary or permanent pores and eventual loss of cell viability by a mechanism known as electroporation (Zimmermann, 1986; Zimmermann, Pilwat, Beckers, & Riemann, 1976). The electric field intensity has to exceed a critical strength for electroporation to occur (Barbosa-Canovas & Sepulveda, 2005). It is therefore thought that, if PEF is applied to a beef muscle and the electric field exceeds the critical limit, it could alter muscle fibres and affect various quality attributes such as tenderness, water holding capacity and colour. Work carried out by Gudmundsson and Hafsteinsson (2001) showed that PEF at low field strength (1.36 kV cm^{-1}) affects the microstructure and texture of chicken and fish. The same research group further showed that PEF treatments caused gaping in the microstructure of salmon samples which led to collagen and other cell fluids to leak into extracellular space (Gudmundsson & Hafsteinsson, 2001).

Although viewed as a "non-thermal" technology, some of the PEF energy input is transformed to heat during processing which can result in mild ohmic heating of the food (Lindgren, Aronsson, Galt, & Ohlsson, 2002). The combination of heat and electricity could have a thermo-electric effect on the muscle cell membranes (Ortega-Rivas, 2011). Although the heat induced by thermo-electric effect is moderate, the synergistic effect of the two could affect the physical characteristics of the beef.

The potential of PEF technology to enhance cell disruption presents an energy efficient and environmentally friendly alternative method of food processing (Toepfl, Mathys, Heinz, & Knorr, 2006). This technology could be applied to beef muscle, offering fast and cost efficient alterations to the muscle cell structure which could affect tenderness which in turn could be of major benefit to the meat industry.

To date, the effect of PEF processing on tenderness and related quality attributes of beef has not been studied in depth. It is therefore of relevance to carry out a study to understand the effect of PEF treatment on beef quality attributes. The objective of this study was to

* Corresponding author at: School of Agriculture, Food Science and Veterinary Medicine, College of Life Sciences, UCD Dublin, Belfield, Dublin 4, Ireland. Tel.: +353 1 7167710; fax: +353 1 7161149.
E-mail address: james.lyng@ucd.ie (J.G. Lyng).

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compare the effect of PEF and conventional heat treatment inducing similar temperatures on a wide range of quality attributes of beef *Semitendinosus* muscle. The quality attributes investigated included; weight loss, drip loss, instrumental colour and tenderness. Other physiochemical characteristics studied include; water activity (a_w), dielectric properties, water mobility by NMR, myofibril fragmentation index, particle size of the myofibrils, conductivity, and microstructure by light microscope.

2. Materials and method

2.1. Beef samples

Beef *Semitendinosus* (ST) muscle from Limousin cross heifers were obtained at 48 h post mortem from local meat supplier (Kepak, Clonee, Co. Dublin, Ireland). The muscle was stored under refrigeration overnight. After 72 h post mortem, the muscle was trimmed of all visible fat and cut into strips (6×2×2 cm, ~30 g) parallel to the muscle fibre direction using a guided chopping board. Samples were randomly assigned to treatments. Three different ST muscles were analysed.

2.2. Pulsed electric field (PEF) and water bath treatments

Preliminary work on PEF treatment of beef showed that PEF induced weight loss as well as temperature rises in the samples. To separate the effect of PEF treatment from that of temperature increase, four PEF treatments (Table 1) were performed in a laboratory scale PEF system (Elcrack-HPV5, DIL IFT, Quakenbruck, Germany) inducing temperature increases of 5, 13, 22 and 30 °C in the beef samples. These were compared to samples experiencing similar temperature increases induced by conventional heating in a water bath.

Controls with no treatment were included in all experiments and care was taken to ensure that handling conditions for both the PEF and water bath treatments were the same to minimise effects of handling. For subsequent experiments, the PEF treatment (1.9 kV cm^{-1}, 65 Hz, 250 pulses and pulse width of 20 μs (83.6 kJ/kg)) which induced a temperature difference of 22 °C was selected as it was the highest electrical field strength that induced significant weight loss compared to the corresponding ΔT treatment in a water bath.

Energy intake by the treated beef samples was calculated according to Zhang, Barbosa-Canovas, and Swanson (1995) based on:

$$Q = \frac{V^2 t}{Rm}$$

where Q is the energy density (kJ/kg), V is the voltage (kV), t is the treatment time (s) while R is the resistance (ohms) and m is the sample mass (~30 g) (kg).

2.3. Weight loss

Samples were weighed pre and post PEF and water bath treatment. Weight loss was calculated as a % change in weight. Within each batch three pseudo replicates were averaged.

Table 1
PEF treatment parameters, electrical field strength (kV cm^{-1}), energy density (kJ/kg), frequency (Hz), pulse number and pulse width (μs) that induced temperature rises (ΔT) in beef samples.

Electrical field (kV cm^{-1})	Energy density (kJ/kg)	Frequency (Hz)	Pulse no.	Pulse width (μs)	ΔT (°C)
1.1	12.7	152	152	20	5
1.5	37.6	200	200	20	13
1.9	83.6	65	250	20	22
2.8	225.8	5	300	20	30

2.4. Electrical conductivity σ

The electrical conductivity was measured using a hand held electrical conductivity meter. Measurements were taken by inserting the twin probe directly into each meat strip at two different points and at three processing stages: pre- and immediately post-treatment and again after cooling to 4 °C.

2.5. Drip loss

A centrifugation method was used to determine water holding capacity. Diced samples (10 g) were weighed into plastic centrifuge tubes fitted with a wire gauze and filter paper according as described by Farag, Duggan, Morgan, Cronin, and Lyng (2009). Following the centrifugation, the samples were removed from the tubes and reweighed. Drip loss was calculated as a % of the original weight, the average value of three replicates per batch was taken.

2.6. Total expressible fluid (moisture and solid)

Total expressible fluid was calculated for PEF and water bath treated samples using the method of Lee, Whiting, and Jenkins (1987). Sample cubes (2×2×2 cm) were placed between pre dried and weighed 7 cm Whatman filter paper, number 4 (Whatman International Ltd., Maidstone, England), then compressed by 50% of their height using an Instron Universal Testing machine (Model No. 5544, Instron Corporation, High Wycombe, UK) fitted with a load cell of 500 N and flat faced compression head. The filter papers were weighed to determine total expressible fluid, dried overnight in an oven at 105 °C and re-weighed to calculate the % moisture and solids.

2.7. Moisture determination

Moisture content was measured in all the samples by oven drying following AOAC (1995) method number 960.46. Analysis was carried out in triplicate.

2.8. Water activity (a_w)

Water activity was measured using a Novasina Labmaster-a_w meter (Novatron, Horsham, England). Diced meat samples (2 g) were placed into sealed air-tight containers and allowed to equilibrate to 25 °C before measurement. Three measurements were taken per treatment and averaged for data analysis.

2.9. Colour measurements

Hunter Lab colour measurements were performed on samples after PEF and water bath treatment after cooling back to 4 °C using a Minolta colorimeter (Model No. CR-400, Minolta Ltd., Osaka, Japan) pre calibrated for internal light (D65). Measurements were taken on 3 different points per sample. Untreated samples were used as controls. Hue and chroma were calculated using the formulas outlined by Zhang, Lyng, and Brunton (2004).

2.10. Cooking and Texture analysis

Following PEF treatment and water bath heating, the samples were cooked for texture measurements. Before cooking, thermocouples were inserted into the core of each sample which was placed into open top plastic bags. Samples were then cooked in a pre-heated water bath to an internal temperature of 71 °C. Following cooking, the samples were cooled to 4 °C in ice water and refrigerated overnight. The following day the samples were cut into strips of 3×1×1 cm and placed with fibres running at right angle to the flat blade of texture analyser. The maximum shear force (N) was recorded