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Effect of low and high pulsed electric field processing on macro and micro minerals in beef and chicken

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ABSTRACT

The present study investigated the effects of low pulsed electric field (LPEF, 2.5 kV, 200 Hz and 20 μs) and high pulsed electric field (HPEF, 10 kV, 200 Hz and 20 μs) on the levels of 40 macro- and micro-minerals in raw and cooked cold-boned beef loins at 1 and 14 days of post-treatment and in chicken breasts at 1 and 4 days. PEF treatment reduced the concentration of Ca ($P < 0.01$), Na ($P < 0.001$) and Mg ($P < 0.03$) and increased the concentration of Cr ($P < 0.01$) in beef compared to non-treated controls. HPEF chicken breast treated samples had significantly ($P < 0.001$) higher Ni concentration than LPEF and control samples that were not different from both treatment groups. Both LPEF and HPEF treated chicken samples had higher Cu concentrations than control samples. The results suggest that PEF treatment of meat can result in the release of elements from the PEF electrodes and contribute to the mineral status of beef and chicken meat samples. PEF appears to have a differential effect on mineral content according to the type of meat. The nutritional and safety consequences of these effects need to be evaluated.

1. Introduction

The use of pulsed electric field (PEF) technology has been suggested to impart a wide range of beneficial effects in food processing. Such effects include ensuring product safety through electroporation of microorganisms present, to gaining better sensory attributes and improved nutritional value and yield of the treated products (Barba et al., 2015). PEF technology is attracting industry and academia interest due to the extremely short treatment time (processing time is seconds) and the absence of heat generation during processing. The ability of PEF to modify the texture of biological materials has attracted interest in using the technology to improve the tenderness of meat (Arroyo et al., 2015; Bekhit, Suwandy, Carne, van de Ven, & Hopkins, 2016; Bekhit, van de Ven, Hopkins, Suwandy, & Fahri, 2014; Faridnia et al., 2015; Faridnia, Bekhit, Niven, & Oey, 2014; Khan et al., 2017; O'Dowd, Arimi, Noci, Cronin, & Lyng, 2013; Suwandy, Carne, van de Ven, Bekhit, & Hopkins, 2015a,b,c,d). Generally, positive improvement in meat tenderness was reported by some studies (Bekhit et al., 2014, 2016; Suwandy et al., 2015a,b,c,d) while others found no improvement in meat tenderness (Arroyo et al., 2015; Faridnia et al., 2014, 2015; Khan et al., 2017; O'Dowd et al., 2013). Several reasons related to experimental design and sampling procedures may have led to this variation in the outcomes as has been discussed in Bekhit, Suwandy, Carne, Ali, and Wang (2017). Since the mechanism of action of PEF is due to its effects on cellular changes and increased permeability of the cellular structure derived mainly by electroporation, it is of interest to evaluate the impact of PEF treatment on important nutrients including nutritional minerals, such as iron (Fe), zinc (Zn), potassium (K) and phosphorus (P), which have been reported for beef (Khan et al., 2017) and chicken (Khan et al., 2016). The modification of cellular structure might cause loss of minerals due to purge loss during aging caused by lack of a physical barrier and diffusion, or during cooking as a result of pressure caused by protein denaturation. Lower ($P < 0.01$) P, K and Fe concentrations were found in high PEF (10 kV, 200 Hz and 20 μs) treated beef samples compared to low PEF (2.5 kV, 200 Hz and 20 μs), but this was not found in chicken breasts, suggesting differential PEF effects in various biological materials (Khan et al., 2016, 2017). Another under-investigated issue is the electrode corrosion and potential migration of electrode

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Table 1
List of minerals investigated in control non-treated and pulsed electric field treated beef and chicken samples.

Mineral	Chemical symbol	Mineral	Chemical symbol
Aluminium	Al	Lithium	Li
Antimony	Sb	Lutetium	Lu
Arsenic	As	Magnesium	Mg
Barium	Ba	Manganese	Mn
Boron	B	Molybdenum	Mo
Cadmium	Cd	Neodymium	Nd
Caesium	Cs	Nickel	Ni
Caesium	Ce	Praseodymium	Pr
Calcium	Ca	Rubidium	Rb
Chromium	Cr	Samarium	Sm
Cobalt	Co	Selenium	Se
Copper	Cu	Silver	Ag
Dysprosium	Dy	Sodium	Na
Erbium	Er	Strontium	Sr
Europium	Eu	Thulium	Tm
Gadolinium	Gd	Tin	Sn
Gallium	Ga	Uranium	U
Holmium	Ho	Vanadium	V
Lanthanum	La	Ytterbium	Yb
Lead	Pb	Yttrium	Y

material into the real food systems. Loeffler (2006) reviewed the generation and application of high intensity PEF and reported that the waveform can have a detrimental effect on electrode corrosion and subsequent contamination of treated materials. The use of a monopolar waveform can lead to a series of issues with stainless steel electrodes (e.g. electrode corrosion, electrolysis and formation of deposits on the electrode surface). However, the use of a bipolar waveform can minimize the corrosion of the electrode (Loeffler, 2006). More recently, Pataro, Falcone, Donsì, and Ferrari (2014) investigated the release of Fe, chromium (Cr), nickel (Ni) and magnesium (Mg) from stainless steel electrodes in buffers. The authors reported increased metal release with an increase in total specific energy input and in the presence of halides (such as chlorides) in the treated material. Since information on the migration of elements from stainless steel electrodes into PEF treated food is scare, it was decided to analyze the beef and chicken samples for a larger set of minerals (Table 1). Therefore, the aim of the present study was to investigate whether migration of minerals from stainless steel electrodes occurs in raw and cooked cold-boned beef *M. Longissimus et lumborum* (LL) at 1 and 14 days post-treatment and chicken breasts at 1 and 4 days post-treatment after being subjected to low PEF (LPEF, 2.5 kV, 200 Hz and 20 μs) and high PEF (HPEF, 10 kV, 200 Hz and 20 μs) treatment.

2. Materials and methods

2.1. Beef loin and chicken breast samples

Cold-boned loins (*M. Longissimus et lumborum*, LL) were obtained from dairy cows (n = 6) with an average age of 6.2 ± 0.4 years and cold carcass weight of 204.2 ± 21.8 kg. The animals were raised on pasture and slaughtered by the Alliance Group Limited (Pukeuri plant, Oamaru, NZ). The description of the carcass processing and the treatments has been reported in Khan et al. (2017). Skinless chicken breasts (n = 36, average breast weight 188.5 ± 19.4 g) were obtained chilled at 10 °C from Santa Rosa company (Islington, Christchurch, New Zealand) at 24 h post-mortem. Teflon knives were used in the preparation of the samples.

2.2. PEF treatment

An Elcrack-HPV5 (DIL, German Institute of Food Technologists, Quakenburck, Germany) PEF system was used in batch mode to treat the meat samples in a treatment chamber with dimensions of 13 × 8 × 5 cm (having an effective sample-electrode contact area of 52 cm^2). The average weight of the treated chicken breasts was adjusted to 360.1 ± 3.4 g by trimming, whereas average weight of the beef samples was 362.3 ± 10.5 g. The samples were in direct contact with the electrodes and the treatment chamber was cleaned between treatments using deionized water. The distance between the electrodes (5 mm thick) was 8 cm and the electrodes were separated by a Teflon insulating material. PEF treatment parameters (10 kV and 200 Hz) were chosen based on earlier observations that PEF treatment parameters higher than this can generate an undesirable slight cooking effect on the edges of the meat samples (Bekhit et al., 2014). The total specific energy for the LPEF and HPEF was 12.4 kJ/kg and 149.8 kJ/kg, respectively, as determined using the equation reported by Arroyo et al. (2015):

$$Q = \frac{V^2 \tau \sigma A}{d} \times \frac{N}{m}$$

where V is the input voltage (V), τ is the pulse width (s), σ is the average conductivity of the samples (S/cm), A is the electrode contact area (cm^2), d is the distance between the electrodes (cm), N is the number of pulses and m is the mass of the sample (kg).

2.2.1. Beef samples

The sample treatments were as follows; control 1 day post treatment (con 1); control 14 day post treatment (con 14), low PEF 1 day post treatment (2.5 kV, 200 Hz and 20 μs; total treatment time = 30 s; LPEF 1), low PEF 14 day post treatment (2.5 kV, 200 Hz and 20 μs; total treatment time = 30 s; LPEF 14), high PEF 1 day post treatment (10 kV, 200 Hz and 20 μs; total treatment time = 30 s; HPEF 1) and high PEF 14 day post treatment (10 kV, 200 Hz and 20 μs; total treatment time = 30 s; HPEF 14). After treatments, the samples were individually vacuum-packed and stored at 4 °C for either 1 or 14 days post-treatment times. On the day of the assigned post-treatment time subsamples were obtained for measurements of various quality attributes in raw and cooked samples as reported in Khan et al. (2017). Subsamples were freeze-dried and used for mineral analysis. The concentrations of P, K, Fe and Zn were reported in Khan et al. (2017) and the analysis was repeated to gain further insight of other micro and macro minerals (Table 1). Control-heated samples were prepared but they showed no differences compared to the control untreated samples and thus were not reported.

2.2.2. Chicken samples

The chicken breast samples were randomly assigned to various treatments as follows: [control 1 day post-treatment (con 1); control 4 day post-treatment (con 4), low PEF 1 day post-treatment (2.5 kV, 200 Hz and 20 μs; total treatment time = 30 s; LPEF 1), low PEF 4 day post-treatment (2.5 kV, 200 Hz and 20 μs; total treatment time = 30 s; LPEF 4), high PEF 1 day post-treatment (10 kV, 200 Hz and 20 μs; total treatment time = 30 s; HPEF 1) and high PEF 4 day post-treatment (10 kV, 200 Hz and 20 μs; total treatment time = 30 s; HPEF 4)]. The total specific energy delivered by the low and high PEF was 6.0 kJ/kg and 73 kJ/kg, respectively. After treatments, the samples were individually vacuum-packed and stored at 4 °C for either 1 or 4 days post-treatment times. On the day of the assigned post-treatment time subsamples were obtained for measurements of various quality attributes in raw and cooked samples as reported in Khan et al. (2016). The samples were cooked from frozen state in a water bath at 80 °C. Vacuum packed meat samples were immersed individually in the water bath until they attained an internal temperature of 75 °C (Khan et al., 2016). The internal temperature of the meat was measured individually by using a Fluke type K temperature probe attached to a Fluke 52 meter (Fluke Corporation, Everett, WA, USA). Subsamples were frozen at − 80 °C for 48 h and then freeze-dried at − 46 °C under pressure of 7×10^{-3} mbars for 4 days using a Labconco FreeZone 12 Plus