LWT - Food Science and Technology 59 (2014) 1054–1060

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

The use of pulsed electric fields for accelerating the salting of pork

Ciara K. McDonnell [a, b], Paul Allen [a], Fanny S. Chardonnereau [c], Joshua M. Arimi [b], James G. Lyng [b, *]

[a] Department of Food Chemistry and Technology, Teagasc Food Research Centre, Ashtown, Dublin 15, Ireland
[b] School of Agriculture and Food Science, University College Dublin, Dublin 4, Ireland
[c] AgroSup Dijon, 26 Boulevard Docteur Petitjean, 21079 Dijon, France

ARTICLE INFO

Article history:
Received 6 November 2013
Received in revised form
22 May 2014
Accepted 27 May 2014
Available online 5 June 2014

Keywords:
Salting
Electroporation
Pulsed electric fields processing

ABSTRACT

The efficiency of PEF as a pre-treatment for accelerating the salting (175 kg/m^3 NaCl) of pork was assessed through PEF treatments of varying energy densities (22.6–181.1 kJ/kg). This was achieved through a 2 × 2 × 2 factorial design of field strength (1.2 or 2.3 kV/cm), frequency (100 or 200 Hz) and pulse number (150 or 300 pulses). NaCl and water content (kg/kg) acted as indicators for increased saline diffusion. Weight change, pH, cook loss, water-binding capacity (WBC) and texture profiles were also assessed. PEF at 2.3 kV/cm caused greater weight loss than 1.2 kV/cm ($p < 0.05$). Two treatments (1.2 or 2.3 kV/cm at 100 Hz for 300 pulses) increased the NaCl content of samples ($p < 0.05$) above the control. A similar trend was evident for cook loss whereby an interaction of 100 Hz and 300 pulses gave the highest value. Within PEF treatments, 100 Hz resulted in greater water content than 200 Hz ($p < 0.05$). There was no significant effect of PEF on weight change post-curing, WBC or texture profiles of samples. Theses findings indicate that a potential may exist for reduced curing time through PEF, however further work on the optimisation of treatment parameters is required.

1. Introduction

The addition of NaCl to food reduces water activity and prevents microbial spoilage. In meat processing, NaCl also performs textural and quality functions (Feiner, 2006,). Depending on the end-product, the concentration of NaCl in brine will vary from 0.05 to 0.08 kg/kg in injection brines, 0.12–0.20 kg/kg in cover brines or in dry format for dry-cured hams (Toepfl & Heinz, 2007). Regardless of the method used to cure meat, the diffusion and equalisation of NaCl throughout the muscle is slow. This in part, is due to the increased resistance to mass transfer exerted by cell membranes (Janositz, Noack, & Knorr, 2011). While several studies have aimed to accelerate meat curing, rarely is cell membrane induced resistance accounted for. Vacuum tumbling (Hayes, Kenny, Ward & Kerry, 2007) and ultrasound (Siró et al., 2009) have been shown to accelerate mass transfer in meat through various mechanisms. The mechanical actions of tumbling ensure even brine distribution while the added effect of a vacuum compresses residual gases in pores leading to infiltration of brine (Hayes et al., 2007). Ultrasound has been shown to disrupt the meat matrix but other mechanisms such as acoustic streaming and cavitation phenomena such as shock-waves at a solid interface also enhance mass transfer (Siró et al., 2009). Furthermore, studies involving freeze-thaw curing have shown that ice-crystal induced cell permeation can accelerate infusion of brine, thus reducing processing times (Barat, Grau, Ibáñez & Fito, 2005).

Pulsed electric fields (PEF) is a non-thermal technology which has received attention for its cell membrane permeablisation potential. When the food is placed between two electrodes which send repeated short pulses of high voltage electricity, pores may be formed in cell membranes. This mechanism of electroporation occurs when the transmembrane potential exceeds a critical value of 1 V (Zimmerman, 1996). This may have altering effects on the food texture and water-holding properties (Gudmundsson & Hafsteinsson, 2001) or enhance mass transfer processes (Janositz et al., 2011). Furthermore, due to the technology being classified as non-thermal, it is reported that foods retain high quality after PEF processing (Ho & Mittal, 2000). This has led to a review of PEF as an alternative technique for liquid food pasteurisation (Ho & Mittal, 2000). More recently, the potential of PEF to accelerate mass transfer processes in potato (Janositz et al., 2011; Lebovka, Praporscic, & Vorobiev, 2004) apples and carrots (Eshtiaghi & Knorr, 2002; Lebovka et al., 2004) has been studied. Eshtiaghi and Knorr (2002) found an increased extraction yield from sugar

* Corresponding author. Tel.: +353 1 7167710; fax: +353 1 7161149.
E-mail address: james.lyng@ucd.ie (J.G. Lyng).

http://dx.doi.org/10.1016/j.lwt.2014.05.053
0023-6438/

beet at rates of 2–3 times faster than conventional thermal treatment.

Nonetheless, studies of PEF on solid foods such as meat are lacking (Gudmundsson & Hafsteinsson, 2001; O'Dowd, Arimi, Noci, Cronin & Lyng, 2013). The potential of PEF in meat processing was proven when Toepfl and Heinz (2007) showed that PEF treatment (3 kV/cm; 5 kJ/kg) of pork prior to immersion in cover brine (0.08 kg/kg nitrite salt) could improve diffusion of salt and nitrate in pork haunches. There have also been suggestions that PEF can potentially fragment myofibrils (O'Dowd, Arimi, et al., 2013) and cause gapping within the muscle structure (Gudmundsson & Hafsteinsson, 2001) which could aid the diffusion process. Meat integrity may be affected by PEF in a manner similar to that of ice crystals caused by cell permeablisation during freezing and thawing. Freeze/thaw operations are time consuming and require considerable energy inputs and storage space, therefore a rapid process like PEF could be more cost efficient (Saulis, 2010; Toepfl & Heinz, 2007).

Nonetheless, studies on process optimisation are essential before novel applications of PEF reach realisation. Electroporation is dependent on many factors such as PEF parameters (pulse amplitude, duration, number), cell parameters (size, shape, orientation) and membrane parameters (temperature, ionic strength) (Saulis, 2010), therefore finding an optimum combination of conditions could save time and energy. Although PEF is classified as a non-thermal technology, often temperature rises may occur due to the conversion of electrical energy to heat energy. This thermo-electric effect could have an effect on the meat quality attributes of colour, water-holding capacity and texture (O'Dowd, Arimi, et al., 2013) which are important quality traits for consumers. This study aims to assess the effect of several PEF parameters (field strength, frequency and pulse number) on saline migration and assess the impact of these treatments on the meat quality characteristics.

2. Materials & methods

2.1. Sample preparation and treatment

Pork *M. Longissimus thoracis et lumborum* (LTL) were obtained from a local slaughter plant at 48 h post-mortem. The pH was recorded at three points along the length of the muscle by direct insertion of a glass pH electrode EC-2010-11 (Refex sensors Ltd., Westport, Co. Mayo, Ireland) and only muscles of pH 5.5–5.8 throughout were used. All visible fat and connective tissue was removed. Using a cutting guide, nine samples (6 × 2 × 2 cm, 30 ± 0.5 g) were cut with fibre direction parallel to the long axis. Samples were randomly assigned to PEF pre-treatments prior to salting according to Table 1. The PEF equipment (Elcrack-HPV5, DIL IFT, Quakenbruck, Germany) had a maximum output voltage of 25 kV, pulse width of 4–32 μs and frequency of up to 1000 Hz. The power was supplied through a square pulse with alternating polarity. The batch chamber had a constant electrode gap of 60 mm. Parameters of field strength, frequency and pulse number were varied in a 2 × 2 × 2 factorial experimental design (Table 1). The pulse width was set at 20 μs. Parameters were chosen following preliminary trials which assessed factor combinations resulting in a range of field strengths while maintaining temperature changes below 20 °C and not detrimentally affecting sample appearance. Samples were cooled to 4 °C prior to saline introduction. A non-PEF treated sample, which underwent the same handling conditions, acted as the control. Energy density values (Fig. 1) were calculated using Eqn. (1), (Zhang, Barbosa-Canovas, & Swanson, 1995).

$$Q = \frac{V^2 t_{PEF}}{Rm} \quad (1)$$

Where Q is the energy density (kJ/kg), V is the voltage (kV), t_{PEF} is the PEF treatment time (s), R is the resistance (ohms) and m is the sample mass (kg). Treatment exposure time is the product of pulse number × pulse width (Mittal & Griffiths, 2005). This was equal to 3 ms or 6 ms where the pulse numbers were 150 and 300, respectively. The resistance was calculated according to Eqn. (2)

$$R = \frac{d}{\rho A} \quad (2)$$

Where d is the distance (m) between the electrodes, ρ is the resistivity (Ωm) and A is the area of the electrode (m^2). The resistivity was calculated as the inverse of conductivity (S/m), considering the average conductivity of lean pork tissue to be 0.693 S/m (Shirsat, Lyng, Brunton, & McKenna, 2004). The total processing time (t_{total}) is calculated as the number of pulses divided by the frequency.

After PEF treatment, the sample weight and temperature were recorded and samples were immersed in individual 150 cm^3 containers with 110 cm^3 saline (175 kg/m^3 NaCl) for 30 min. Constant agitation of the brine was ensured by placing samples on a platform shaker (Stuart SSL2, Bibby Scientific Limited, 180 Staffordshire, UK) at 200 cycles per minute. Following salting, samples were rinsed with deionised water, blotted dry, reweighed, vacuum packed and stored (4 °C) until further analysis. Due to the small sample size, many separate batches had to be processed for analysis. A batch was processed for texture profile analysis, a separate batch for cook loss, WBC, NaCl and moisture analysis and a further batch for total viable counts and lipid oxidation. Overall, the trial was replicated in triplicate for each day of storage (1, 7 and 14 days).

Table 1
Pulsed electric field (20 μs) pre-treatments (t_{PEF} = 3–6 ms) for salted (17.5% w/w, 30 min) pork samples.

Treatment	Field strength (kV/cm)[a]	Frequency (Hz)	Pulse no.	Processing time
0	0.0	0	0	0
1	1.2	100	150	1.5
2	2.3	200	300	1.5
3	1.2	200	150	0.7
4	1.2	200	300	1.5
5	2.3	100	150	1.5
6	2.3	100	300	3.0
7	1.2	100	300	3.0
8	2.3	200	150	0.7

[a] Applied voltage for 1.2 kV/cm = 7 kV; applied voltage for 2.3 kV/cm = 14 kV.

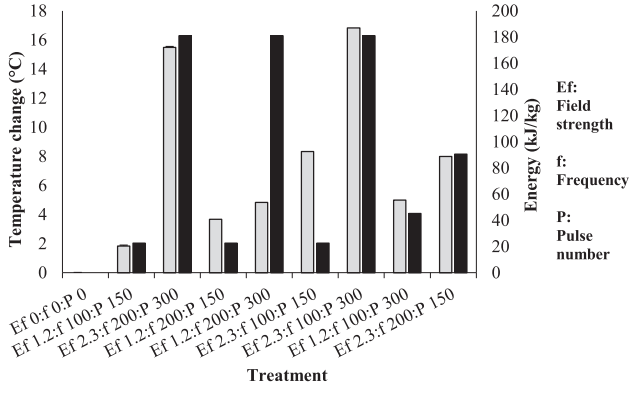

Fig. 1. Temperature changes (°C) in meat and energy densities (kJ/kg) according to PEF treatment.