Innovative Food Science and Emerging Technologies 37 (2016) 68–73

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

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

Effect of freezing under electrostatic field on the quality of lamb meat

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ARTICLE INFO

Article history:
Received 29 November 2015
Received in revised form 13 April 2016
Accepted 27 July 2016
Available online 29 July 2016

Keywords:
Electrostatic field
Freezing
Lamb meat
Microstructure

ABSTRACT

The objective of this study was to investigate the effects of electrostatic field treatment on the quality attributes of frozen lamb meat. The static external electric field was applied at the intensities of $E = 0–5.8 \times 10^4$ V/m during freezing at −20 °C. Following freezing under electrostatic field, meat samples were thawed and their quality characteristics such as drip loss, texture, and colour were assessed by instrumental methods. Light microscopy technique was used to investigate the microstructure of meat. Results showed that electrostatic field application during freezing led to the significant microstructural changes in meat tissue. The average ice crystal size in the meat samples frozen under 5.8×10^4 V/m electric field decreased up to 60% in comparison to the conventional freezing process. It was also found that the drip loss decreased with increasing the electrostatic field strength. The colour and hardness of the meat were not significantly influenced by electric field.

Industrial relevance: This study gives significant information about the effect of electrostatic freezing on the quality of meat. It shows the effectiveness of electrostatic for decreasing the size of ice crystals and helps maintain the quality of meat during freezing. Since this method requires less energy and causes less damage to food the industrial application of this technology is growing.

1. Introduction

Freezing is one of the oldest and most widely used methods of food preservation, which allows preservation of taste, texture, and nutritional value in foods better than any other method (Delgado & Sun, 2001). The quality of frozen products depends on the number of ice crystals as well as the size and the distribution of ice crystals inside the material (Zhu, Ramaswamy, & Le-Bail, 2005a, 2005b). Therefore, there have been numerous studies performed to determine the best method for increasing the number of ice crystals or reducing their size. These can be achieved either by increasing the freezing rate or applying new emerging technologies e.g. high pressure freezing (Chevalier, Le-Bail, & Ghoul, 2000; Su et al., 2014; Zhu et al., 2005a, 2005b)., ultrasound (Cheng, Zhang, Xu, Adhikari, & Sun, 2015; Kiani, Zhang, Delgado, & Sun, 2011; Kiani, Zhang, & Sun, 2013; Kiani et al., 2013), magnetic electric field (Abedini et al., 2011; Kaku et al., 2010; Mohanty, 2001), radio frequency (Anese et al., 2012) or electrostatic field (ESF) treatment.

Among them, the industrial application of electrostatic field seems to be promising since it can be utilized to control ice nucleation and applied remotely and uniformly over the entire sample (Orlowska, Havet, & Le-Bail, 2009; Stan, Tang, Bishop, & Whitesides, 2010). In addition, electrostatic field is a cost effective system that is easy to operate and could be easily integrated with commercially available freezing equipment (Le-Bail, Orlowska, & Havet, 2011; Xanthakis, Havet, Chevallier, Abadie, & Le-Bail, 2013).

Electrostatic fields are constant fields, which do not change in intensity or direction over time. Electrostatic field system must be designed so that it can operate at high electric field strength and dielectric breakdown inside the system must be prevented (Alkhafaji & Farid, 2010; Wei, Xiaobin, Hong, & Chuanxiang, 2008).

Two explanations based on molecular dynamic simulation and thermodynamic laws have been proposed to describe the mechanism of crystallization process under electric field. According to the molecular dynamic simulation, water has a dipole moment due to the oxygen being slightly negative and the hydrogen on the other side being more positive. In the presence of an electric field, the water molecules tend to align with the field. Based on molecular dynamic approach, applying a sufficiently high DC electric field ($1.0–1.5 \times 109$ V/m) to the bulk and clusters of water, showed an abrupt structural change including, all molecular dipoles point to the directions less than 90° with respect to the electric field vector, enhancement of the molecular reorientation rates and hydrogen bonds being stronger along the field than along orthogonal directions (Shevkunov & Vegiri, 2002; Vegiri, 2004a, 2004b). These findings are in accord with the results of Matsutomo, Saito, and Ohmine (2002) which indicate that ice nucleation occurs when a sufficient number of relatively long-lived hydrogen bonds develop

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http://dx.doi.org/10.1016/j.ifset.2016.07.028
1466-8564/

spontaneously at the same location to form a fairly compact nucleus. In addition to the above-mentioned approach, another explanation for the influence of electrostatic field on the freezing was proposed by Le-Bail et al. (2011) based on the thermodynamic laws. They showed that the energy barrier for a phase transition is reduced by applying the external electric field with strength of several kilovolts per meter and accordingly, the critical radius which corresponds to the size of a stable ice crystal is also shifted to lower values.

The occurrence of this phenomenon in freezing of liquid solution such as water and alcoholic solution was reported recently by Wei et al. (2008); Orlowska et al. (2009) and Le-Bail et al. (2011). They found that the nucleation temperature was shifted towards higher values (decrease in the magnitude of supercooling) with increasing the applied voltage. Their experimental results also revealed that utilization of sufficiently high electrostatic field is a reliable method to control ice nucleus formation.

The most recent study of Xanthakis et al. (2013) showed the impact of electrostatic field on real food system. They studied the effect of electrostatic field on pork tenderloin muscle and found that by increasing the strength of the electrostatic field, the degree of supercooling was reduced and the microstructure analysis of meat tissue exhibited a better cellular structure. The average equivalent circular diameter of the ice crystals was significantly reduced with increasing ESF.

The noticeable impact of electrostatic field on the nucleation temperature and ice crystals size in aqueous solution and solid food has been established in the literature. However, further research is still needed to investigate the effect of freezing under ESF on food quality.

This research is part of a study on application of ESF during freezing of lamb meat. It was designed to collect information about quality changes of this product such as texture, colour and ice crystal size distribution in frozen meat during freezing under ESF compared with conventional still air method.

2. Materials and methods

2.1. Materials

The Lamb sirloin meat (*Gluteus medius*) was purchased from the local supermarket (Isfahan, Iran) and stored at 4 °C until use. The samples were prepared in the cylinders form with a diameter of 10 mm and height of 10 mm. The average weight of meat samples was 2.3–2.5 g. The total moisture content was determined by the drying method (AOAC, 1995).

2.2. Freezing under electrostatic field

An experimental set up similar to the one used by Orlowska et al. (2009) was used in this study with a modification on cooling-heating system. The main experimental apparatus to produce electrostatic field consisted of DC voltage generator with output voltage up to 50 kV (LS50 kV-5 mA, China), one pair of cooper plate electrodes with the dimensions of 50 × 50 and 65 × 65 mm placed in parallel as upper and lower electrodes, respectively. The distance between electrodes was determined by the sample height (10 mm) and upper electrode placed 2 mm above the sample surface to avoid direct contact and electrical connection between sample and electrode. Sample holder, which was shown in Fig. 1 was made of polyethylene with following dimension: 80 × 80 × 18 mm. The meat sample was installed in a cylindrical cell located in the center of sample holder (measurement cell). The sample holder was pre-cooled to 5 °C in a cold incubator for one hour before the start of the measurement.

Temperature changes in the geothermal center of the sample were recorded with a data logger (Delta-T Devices Ltd., Cambridge, England) coupled with computer and thermocouples type-K. To avoid interference between the thermocouple signals with electric field, temperature measurement was done intermittently (every 100 s). The power supply was cut off for 3 s when recording the temperature. The experimental set up was placed inside a freezing tunnel with forced air circulation at −20 °C. The applied voltages were 0, 4, 8 and 12 kV. After freezing the samples were weighted and covered with a polyethylene film to avoid moisture evaporation and let in resting condition in cold incubator (Wisecube, WIG-105, Korea) at 5 °C for 3 h, then analyzed for colour, drip loss and texture.

The geometry of electrostatic field treatment that we used to generate electrical fields is more complicated than infinite parallel-plate capacitor. Therefore the electric field strength was calculated by modeling the experimental system using Maxwell equations and solved

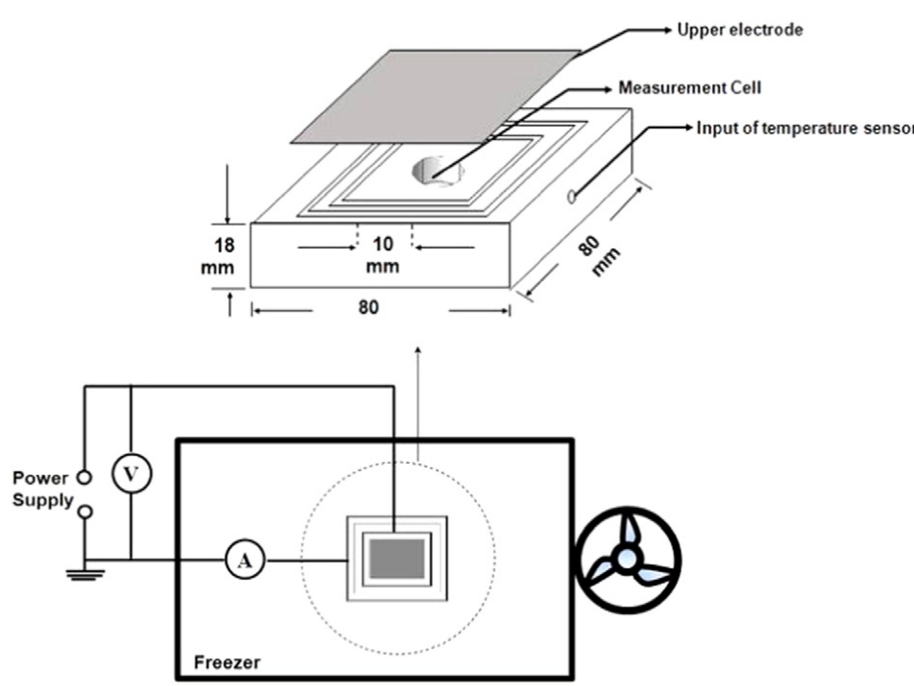

Fig. 1. Scheme of the experimental set-up and sample holder.