

An assessment of the impact of pulsed electric fields processing factors on oxidation, color, texture, and sensory attributes of turkey breast meat

Cristina Arroyo, Sara Eslami, Nigel P. Brunton, Joshua M. Arimi, Francesco Noci, and James G. Lyng¹

School of Agriculture and Food Science, University College Dublin, Dublin 4, Ireland

ABSTRACT Pulsed electric fields (PEF) is a novel nonthermal technology that has the potential to cause physical disruption to muscle tissue which in turn could alter the sensorial aspects of meat in both a positive (e.g., enhanced tenderization) and a negative way (e.g., off-flavor development). If there is a risk of off-flavor development it should be identified prior to embarking on an extensive investigation on PEF in meat tenderization and turkey meat was chosen for this purpose as it is particularly prone to oxidation. The objective of this study was to investigate the effect of various PEF treatments on the quality attributes of turkey breast meat. Turkey breast meat obtained 1 d post-slaughter was treated in a batch PEF chamber with increasing electric field strength up to 3 kV/cm and analyzed for lipid oxidation by thiobarbituric acid reactive substances assay (TBARS) with up to 5 d storage at 4°C in aerobic conditions. In a separate exper-

iment, turkey breast meat samples were exposed to PEF under various combinations of pulse number, frequency, and voltage. Following PEF treatments weight loss, cook loss, lipid oxidation, texture, and color were assessed by instrumental methods. A sensory analysis was also performed to determine consumer acceptability for color, texture, and odor of the samples. Lipid oxidation in all PEF-treated samples progressed at the same rate with storage as the untreated samples and was not found to be significantly different to the control. Under the conditions examined PEF treatments did not induce differences in instrumentally measured weight loss, cook loss, lipid oxidation, texture, and color (raw and cooked) either on fresh or frozen samples. However, the sensory evaluation suggested that panelists could detect slight differences between the PEF-treated samples and the controls in terms of texture and odor.

Key words: pulsed electric fields, turkey breast meat, lipid oxidation, texture, sensory analysis

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INTRODUCTION

Pulsed electric fields (PEF) is a processing technology that uses short pulses of electrical energy at high voltage delivered through a material placed between 2 electrodes. Based on the dielectric rupture theory, the external electric field can induce a potential difference across the cell membrane. When this transmembrane potential reaches a threshold value, the electroporation in the cell membrane occurs which increases its permeability. Depending on multiple factors such as the electric field strength and the pulse number the electroporation effect is reversible or irreversible (Angersbach et al., 2002). PEF has been proven as an effective method for irreversible permeabilization of cell membranes in microbial cells and plant and animal cells without a significant temperature increment and requiring low cost operation (Toepfl et al., 2006). Applying PEF 1) to liquid food to inactivate both spoilage and

pathogenic microorganisms and extend their shelf life with minimal impact on the sensory quality, and 2) as a pretreatment before mechanical pressing or extraction to enhance the extraction yield of juices from fruits and vegetables or intracellular valuable compounds such as sucrose or colorants has been extensively investigated. However, to the knowledge of the authors, the number of research studies focused on the application of PEF to food muscle cells is still scarce (Gudmundsson and Hafsteinsson, 2001, Lopp and Weber, 2005; Toepfl, 2006; Hoffmann et al., 2009; O'Dowd et al., 2013; Bekhit et al., 2014; Faridnia et al., 2014a,b; McDonnell et al., 2014; Arroyo et al., 2015).

PEF processing has been demonstrated to induce changes in the structure and texture of meat, potentially improving its functional properties or aiding in the development of new products (Gudmundsson and Hafsteinsson, 2001, Toepfl et al., 2006; Faridnia et al., 2014b; McDonnell et al., 2014). However, PEF could also induce unfavorable changes that do not normally occur in meat. Chilled raw meat is usually oxidatively stable but mincing, cooking, and other processes disrupt muscle cell membranes facilitating the interaction between lipid oxidation catalysts (heme/nonheme

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¹Corresponding author: james.lyng@ucd.ie

iron) and unsaturated fatty acids, resulting in generation of free-radicals and lipid hydroperoxides. Peroxides are susceptible to breakdown into secondary products such as acids, alcohols, aldehydes, and ketones which are major contributors to the oxidized, rancid off-odor known as warmed-over flavor (Byrne, 2000). Thereby, PEF treatment could have the potential to cause cell membranes damage promoting the onset of lipid oxidation ultimately decreasing the nutritional quality and safety of the meat.

The rate and extent of oxidation is dependent on many factors including meat composition, fatty acid content, level of unsaturation, presence of antioxidants, heat, and other processing conditions (Danowska-Oziewicz et al., 2009). Among various types of meat, turkey meat is particularly prone to oxidation due to its high levels of polyunsaturated fatty acids present in its tissues (Tichivangana and Morrissey, 1985), its high concentration in free iron and, for some authors, to its weak ability to store dietary vitamin E (Mercier et al., 2001).

There are no previous studies reporting the effect of pulsed electric fields on turkey meat. In this study selected quality attributes of turkey meat including oxidative stability, water loss, color, and texture was investigated after the exposure of turkey breast samples to PEF.

MATERIALS AND METHODS

For this study turkey breast meat obtained 1 d postslaughter (McCaughy Turkeys, Castleblayney Co., Monaghan, Ireland) was used to carry out 2 different experiments.

Experiment 1

This experiment aimed to assess the effect of PEF on the lipid oxidation of raw and cooked turkey meat samples aerobically stored over 5 d at 4°C. Upon reception, breast meat from 3 turkeys was removed from the bone and cut into 30 slices of 4 × 1 × 1 cm (~5 g) using an automatic slicer and trimmed to size using a metal template. To block across the effect of animal to animal variation (and associated variation in ante-mortem biological factors such as age, sex, and breed), samples from each breast were either assigned as controls (n = 6) or exposed to one of the 4 PEF treatments (n = 6 per treatment). Samples undergoing PEF treatments were treated in a modified batch PEF (lab scale system, ELCRACK-HPV5, DIL, Germany) treatment chamber specifically designed to hold a sample of those specific dimensions (distance between electrodes = 4 cm). Samples were treated with the fiber direction parallel to the electrodes. Voltages of 4.4, 7.6, 9.2, and 12 kV were applied keeping the pulse width (20 μs), frequency (5 Hz), and pulse number (300) constant, which corresponded with associated specific energies of 26, 78, 114, and

194 kJ/kg. Following PEF treatment, samples were individually wrapped in aluminum foil and either stored raw (n = 3 controls + 12 PEF-treated samples) or cooked (n = 3 controls + 12 PEF-treated samples). Cooking was performed in a preheated oven at 200°C until the internal temperature of the meat samples reached 85°C (duration: 3 min and 15 s; end point temperature chosen from Brunton et al., 2000), then cooled by placing them in a bag immersed in ice water. Raw and cooked samples were stored at 4°C for up to 5 d and lipid oxidation analysis was carried out on d 0 (day of PEF treatment), 1, and 5 as described below.

Experiment 2

The second experiment aimed at comparing the effects of various PEF treatment settings on quality attributes of fresh and frozen turkey breast meat. An orthogonal array was designed incorporating 3 levels of 3 factors: voltage (7.5, 10, and 12.5 kV for fresh meat and 14, 20, and 25 kV for frozen meat), pulse number (100, 200, and 300 pulses of 20 μs) and frequency (10, 55, and 110 Hz) with a distance between electrodes of 6 cm. Total specific energies applied ranged from 11 to 94 kJ/kg. Right and left breasts were prepared for the fresh and frozen tests, respectively. Each treatment was performed in duplicate and for each quality attribute tested, 3 different measures were taken from each batch. The results were then averaged to produce one value for each quality attribute. Measurements from untreated controls were also taken in all experiments.

Experiment 2a, fresh meat. The right breast of the turkey crowns were cut into 6 × 2 × 2 cm strips (~30 g) using the guided chopping board and immediately treated by PEF.

Experiment 2b, frozen meat. The left breast of the turkey crowns were cut into 7 × 2.5 × 2.5 cm strips (~55 g) and placed into holders of the same size specifically designed to prevent shape distortion during freezing. The holder and enclosed sample was then placed in a freezer at -18°C for 48 h. Immediately prior to PEF processing the frozen samples were trimmed to fit the dimensions of the PEF treatment chamber (6 × 2 × 2 cm). Samples were treated in the frozen state with the objective of increasing the voltage applied while maintaining the same energy input since the electrical conductivity is lowered upon freezing, and to increase the brittleness of the cellular structure possibly rendering it more susceptible to PEF. Following PEF treatment, samples were covered in cling film and allowed to defrost at 4°C for further analysis.

Quality Parameters

Lipid oxidation. Lipid oxidation of untreated and PEF-treated turkey samples was assessed by measuring the thiobarbituric acid-reactive substances (TBARS) in the samples using the method described by Pearson et al. (1977), with a few modifications. Briefly, a 5 g

minced turkey meat sample was homogenized in 25 mL distilled water using an Ultra turrax T25 (Janke and Kunkel, GmbH, Staufen, Germany) at 9,000 rpm for 1 min. A 3 mL aliquot of the turkey homogenate was added to 3 mL trichloroacetic acid/thiobarbituric acid stock solution (1.14 M trichloroacetic acid, 0.032 M thiobarbituric acid in 0.32 M HCl) in a glass tube and vortex-mixed. Samples were incubated in a water bath at 94°C for 15 min for color development. Following a cooling period of 10 min in ice, samples were centrifuged at 2,500 rpm for 15 min. Absorbance of the supernatant was measured at 535 nm (UVmini-1240, UV-visible spectrophotometer, Shimadzu Corporation, Japan). Results were expressed in milligram malondialdehyde (MDA) per kilogram meat using a standard calibration curve prepared using tetraethoxypropane.

Weight loss. Measurements of sample weight were performed before and after PEF treatments. Weight loss (percent) due to the PEF treatments was calculated as a percentage of the original weight.

Color. Surface color was examined before and after PEF treatments and after cooking using a Minolta colorimeter (Model No. CR-400, Minolta Ltd., Milton Keynes, UK) attached to a Minolta data processor (DP-400) used with a glass light projection tube CR-A33D (with ϕ 22 mm disc). The system settings were: observer, 2 degree; illuminant, D₆₅; measurement aperture, ϕ 8 mm. Hunter 'L' 'a' 'b' measurements (dimensionless) were recorded at 4 locations (3 readings per location) along the center line of the strips. Measurements were taken while samples were placed on a standard background (a grey laboratory bench in this instance).

Cook loss. Water-holding capacity is another important meat quality attribute and can be evaluated by cook loss. Samples were cooked in a preheated oven at 200°C until the internal temperature of the meat reached 85°C. Cook loss (percent) was calculated using sample weight measurements pre- and postcooking, and expressed as a percentage of the sample weight prior cooking. Postcooking weight was measured following cooling and patting to remove cook loss exudate.

Texture. Texture was assessed by Warner-Bratzler shear force measurements, which indicates the maximum shear force (Newtons) required to cut the sample, using the method described by Zell et al. (2010). Cooked samples were cut into 3 × 1 × 1 cm strips for analysis. Shear force measurements were taken using an Instron universal testing machine (Model No. 5544, Instron Corporation, High Wycombe, UK) equipped with a 500 N load cell and accompanying software, Instron Bluehill 2 (Version 2.5). Sample strips were cut using a cross head speed of 50 mm/min with the meat fibers running at right angles to the blade.

Sensory evaluation. A sensory analysis was conducted using cooked samples (6 × 2 × 2 cm) that were previously PEF-treated with the highest voltage (12.5 kV) and largest number of pulses (300) within the constraints of the orthogonal design. The sensory evalua-

tion consisted of 40 untrained panelists and no information on sample treatments was provided prior to consumption. The sensory analysis laboratory was temperature controlled (25 ± 2°C), equipped with controlled lightening and individual booths. A discrimination test was carried out according to the method of Meilgaard et al. (2006) to determine whether panelists could differentiate between untreated and PEF-treated samples for overall color, tenderness, and odor. Each panelist was given 3 samples (2 identical and one different) of cooked turkey meat served in coded plastic cups for color and texture evaluation. For odor evaluation, 10 g finely chopped turkey meat was placed into small coded plastic cups, sealed with parafilm, and allowed to equilibrate to 25 ± 2°C before being presented to the panel members. Panelists were then asked to record the number of the odd sample.

Also an acceptance test was performed to determine the 'affective status' of each sample using a 9-point hedonic scale for tenderness (1 = very tough, 3 = tough, 5 = neither tough nor tender, 7 = tender, 9 = very tender), color (1 = too dark, 5 = just right, 9 = too light), and odor (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely).

Statistical Analysis

Data on the impact of PEF on the lipid oxidation of turkey breast meat during storage (Experiment 1), on the influence of the electric field strength, frequency, and pulse number on various quality attributes of turkey breast meat (Experiment 2) and on the 9-point hedonic scale test was subjected to one-way ANOVA using SPSS Version 20 (Statistical Packages for Social Sciences, SPSS Inc., IBM Company Headquarters, Chicago). Where ANOVA indicated significant differences between samples ($P < 0.05$), a Tukey pairwise comparison of the means was conducted. The discrimination test data was analyzed using a sequential test with the assigned values $\alpha = 0.05$ (probability of stating that a difference occurs when it does not), $\beta = 0.1$ (probability of stating that no difference occurs when it does), $p_0 = 0.33$ (the expected proportion of correct answers when the samples are identical), and $p_1 = 0.5$ (the expected proportion of correct decisions when the odd sample is detected, other than by guess, on half the total number of occasions) according to Meilgaard et al. (2006).

RESULTS AND DISCUSSION

Experiment 1

As described above, this experiment aimed to assess the effect of PEF on the lipid oxidation of raw and cooked turkey meat samples aerobically stored over 5 d at 4°C. Lipid oxidation of meat is an important process which among other effects leads to rapid quality deterioration and development of rancidity due to the

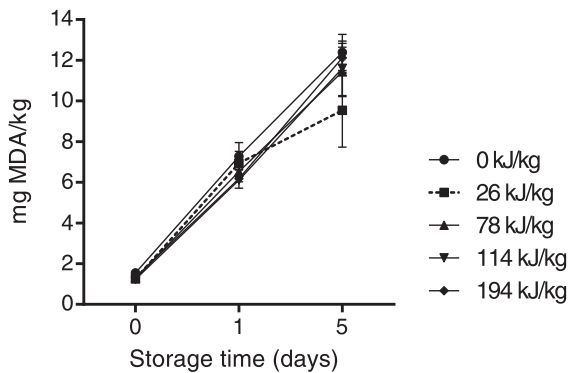


Figure 1. Effect of PEF treatments of increasing energy applied (kJ/kg) on the oxidative stability determined by malondialdehyde (MDA) concentrations (mg/kg) in cooked turkey breast meat stored under aerobic conditions at 4°C. Error bars indicate the SEM values.

production of volatile compounds that can strongly affect its aroma (Whitfield and Mottram (1992)). Poultry meat, in particular, is very sensitive to oxidative deterioration because of its very high content of polyunsaturated fatty acids.

Figure 1 presents the development of lipid oxidation, as determined by MDA concentrations, in the cooked turkey breast meat determined after 0, 1, and 5 d refrigerated storage. As can be seen, refrigerated storage increased levels of MDA in both untreated and PEF-treated breast samples. The initial TBARS values (d 0) showed no differences ($P \geq 0.05$) between the 4 PEF-treated samples and the control accounting for 1.3 mg MDA/kg in average. Between d 0 and 1 a 5-fold increase in TBARS values were observed for all samples ($P \geq 0.05$). A similar increase was observed in the work of Tang and Cronin (2007) with turkey rolls stored at 5°C under aerobic conditions. Other studies on cooked turkey breasts have reported that the sharp increase in TBARS after cooking is due to the susceptibility of the turkey to oxidize while it is still hot and exposed to oxygen (Ahn et al., 1992). After 5 d, lipid oxidation in all the samples progressed at the same rate. The sample subjected to the PEF treatment of 1.1 kV/cm field strength appeared to be more stable to lipid oxidation compared to the control and the other PEF-treated samples, although the difference was found not to be significant ($P \geq 0.05$). TBARS values on d 5 for all treatments averaged 11.5 mg MDA/kg, which is considerably high compared to other studies (Tang and Cronin, 2007; Zell et al., 2010). This may be due to the small size of the sample and the fact that the full sample was used in the analysis method compared to Zell et al. (2010) who separately measured TBARS values for the outer surfaces and center sections of the turkey. Thermal damage to the surface of the sample makes it more susceptible to lipid oxidation than for the center sections when exposed to air during storage (Tang et al., 2005; Zell et al., 2010; Wu and Sheldon, 1988). As expected, the extent of lipid oxidation in the raw meat did not progress at the same rate with storage as the cooked samples (data not shown). In this case, TBARS values

for the raw meat samples (control and PEF-treated) averaged 0.76 mg MDA/kg on d 5, a similar value to that found by Fraqueza and Barreto (2009) in raw turkey meat after 5 d storage under aerobic conditions (0.5 mg MDA/kg). The increased MDA values of cooked samples compared with the raw ones showed that cooking induced lipid oxidation, which is attributed to disruption of muscle cell membranes that facilitate the interaction of unsaturated fatty acids with prooxidant substances (Tichivangana and Morrissey, 1985).

Experiment 2

For this experiment, an orthogonal design was used to assess the effect of various PEF treatment settings on the quality attributes of fresh and frozen turkey breast meat. Tables 1 and 2 include the results for all the quality parameters assessed for both fresh and frozen turkey meat samples, respectively. Temperature before and after PEF treatments was measured achieving a maximum increase of 26°C (meat specific heat capacity = 3.3 kJ/kg°C).

Weight loss. Water content is a qualitative parameter of primary importance in meat industry as well as the sensory characteristics of such a product that are strictly influenced by the binding of water to meat. In fact, an important decrease of water content of the meat can negatively affect the quality attributes such as tenderness, texture, and flavor. Weight losses on account of the PEF treatment for fresh and frozen samples are shown in Tables 1 and 2, respectively. The results for the frozen samples represent a combined weight loss due to PEF treatment per se and the defrosting step. Overall the fresh samples tended to lose more weight (averaged 0.8%) than the frozen samples (averaged 0.07%). However, weight loss due to PEF treatments was not found to be affected by any of the 3 PEF treatment factors studied ($P \geq 0.05$). A weight loss in meat cuts following the application of PEF is well described in the literature (O'Dowd et al., 2013; McDonnell et al., 2014; Bekhit et al., 2014; Faridnia et al., 2014a,b; Arroyo et al., 2015) with values ranging from 0.2% to 3.6% though it has been reported that the purge loss increases by increasing the intensity of the treatment (O'Dowd et al., 2013; McDonnell et al., 2014; Bekhit et al., 2014; Arroyo et al., 2015). Authors have proposed that the fluid loss associated with PEF treatments may be due to the formation of pores in the cell membrane which correlates with an immediate increase in meat conductivity (O'Dowd et al., 2013; McDonnell et al., 2014; Bekhit et al., 2014; Faridnia et al., 2014a).

Cook loss. Together with the weight loss, juice loss following cooking is a measure of great economic importance as cooked meat is sold by weight and also because cook loss is associated with a detriment to juiciness and succulence. Results shown in Tables 1 and 2 demonstrate that there were no differences in cook loss for any

Table 1. Instrumental results for fresh turkey breast meat treated with pulsed electric fields (PEF) under different processing conditions. The standard error of the means (SEM) are included in parentheses.

Instrumental Analysis	Control (n = 6)	PEF Process Factor (pulse width = 20 μ s)											
		Number of pulses					Voltage (kV)					Frequency (Hz)	
		100 (n = 18)	200 (n = 18)	300 (n = 18)	7.5 (n = 18)	10 (n = 18)	12.5 (n = 18)	10 (n = 18)	110 (n = 18)	110 (n = 18)	110 (n = 18)		
Weight loss (%)	NA ²	0.64 (0.33)	0.70 (0.10)	0.89 (0.30)	0.52 (0.08)	1.15 (0.25)	0.56 (0.18)	0.91 (0.32)	0.80 (0.26)	0.52 (0.13)			
Cook loss (%)	11.7 (1.36)	12.9 (1.50)	12.1 (1.65)	10.8 (0.71)	11.7 (1.24)	12.3 (1.43)	11.7 (1.68)	12.9 (1.44)	11.5 (1.78)	11.4 (0.69)			
TBARS (mg MDA/kg) ¹	5.00 (0.16)	3.94 (0.41)	3.42 (0.74)	4.74 (0.52)	3.91 (0.67)	3.59 (0.63)	4.61 (0.22)	4.75 (0.13)	3.48 (0.64)	3.88 (0.56)			
Shear force (N)	18.9 (4.37)	20.2 (2.15)	22.2 (2.29)	25.0 (0.70)	20.6 (2.87)	24.1 (0.20)	22.7 (2.20)	22.3 (2.26)	22.3 (2.30)	22.8 (2.39)			
Raw color	<i>L</i>	43.7 (0.51)	46.7 (1.14)	42.0 (0.83)	41.4 (1.13)	43.52 (0.95)	44.0 (2.55)	42.8 (1.55)	43.7 (0.86)	43.7 (2.83)			
	<i>a</i>	7.43 (0.70)	7.04 (0.47)	7.31 (0.18)	7.50 (1.00)	6.26 (0.42)	7.82 (0.24)	6.61 (0.56)	7.35 (0.56)	7.90 (0.53)			
	<i>b</i>	2.64 (0.26)	3.91 (0.62)	3.98 (0.24)	2.75 (0.29)	3.06 (0.45)	3.94 (0.67)	3.10 (0.47)	3.54 (0.47)	4.01 (0.59)			
Cooked color	<i>L</i>	76.2 (2.78)	82.4 (1.46)	80.7 (2.44)	81.9 (2.71)	80.9 (1.71)	78.9 (1.62)	81.7 (3.21)	83.0 (1.07)	80.3 (1.69)			
	<i>a</i>	5.88 (0.57)	4.35 (0.22)	5.26 (0.52)	5.67 (0.95)	4.35 (0.47)	5.71 (0.70)	4.90 (0.69)	5.00 (0.82)	5.40 (0.66)			
	<i>b</i>	8.46 (0.23)	8.09 (0.46)	7.85 (0.28)	8.29 (0.45)	7.55 (0.10)	8.40 (0.33)	8.27 (0.45)	7.95 (0.51)	8.02 (0.23)			

¹MDA = Malondialdehyde; TBARS = Thiobarbituric acid reactive substances.

²NA = Not applicable.

Table 2. Instrumental results for frozen turkey breast meat treated with pulsed electric fields (PEF) under different processing conditions. The standard error of the means (SEM) are included in parentheses.

Instrumental Analysis	Control (n = 6)	PEF Process Factor (pulse width = 20 μ s)											
		Number of pulses					Voltage (kV)					Frequency (Hz)	
		100 (n = 18)	200 (n = 18)	300 (n = 18)	14 (n = 18)	20 (n = 18)	25 (n = 18)	10 (n = 18)	55 (n = 18)	110 (n = 18)	110 (n = 18)		
Weight loss (%)	NA ²	0.05 (0.01)	0.13 (0.01)	0.06 (0.03)	0.10 (0.03)	0.08 (0.02)	0.06 (0.03)	0.08 (0.02)	0.06 (0.05)	0.09 (0.01)			
Cook loss (%)	10.5 (1.76)	15.6 (0.50)	15.4 (1.12)	13.4 (3.03)	14.6 (2.04)	12.7 (1.30)	17.1 (1.22)	13.9 (1.87)	17.1 (1.42)	13.4 (1.60)			
TBARS (mg MDA/kg) ¹	2.35 (0.13)	2.66 (0.14)	2.68 (0.15)	3.11 (0.46)	2.67 (0.20)	2.67 (0.25)	3.11 (0.40)	2.98 (0.10)	3.05 (0.43)	2.42 (0.10)			
Shear force (N)	21.9 (1.45)	19.6 (2.14)	23.6 (2.98)	20.1 (2.05)	18.9 (1.34)	23.5 (3.62)	20.9 (1.45)	20.6 (1.79)	19.2 (1.31)	23.5 (3.57)			
Raw color	<i>L</i>	44.8 (1.18)	45.2 (0.57)	43.0 (1.57)	45.6 (1.15)	43.1 (1.65)	45.3 (1.25)	44.7 (0.69)	46.1 (0.85)	42.9 (1.54)			
	<i>a</i>	3.98 (0.34)	3.83 (0.33)	3.01 (0.12)	3.47 (0.15)	3.64 (0.22)	3.10 (0.09)	3.61 (0.40)	3.35 (0.34)	3.36 (0.13)			
	<i>b</i>	1.61 (0.38)	1.90 (0.38)	0.65 (0.21)	1.18 (0.26)	1.08 (0.44)	1.26 (0.20)	1.61 (0.53)	1.35 (0.25)	0.76 (0.34)			
Cooked color	<i>L</i>	77.9 (0.87)	77.9 (0.48)	77.0 (2.30)	78.6 (0.53)	76.2 (1.79)	79.6 (0.48)	78.7 (0.95)	78.4 (0.65)	76.4 (1.91)			
	<i>a</i>	3.04 (0.22)	3.23 (0.14)	2.93 (0.29)	3.12 (0.34)	3.44 (0.03)	2.68 (0.15)	3.15 (0.24)	2.81 (0.30)	3.32 (0.18)			
	<i>b</i>	6.57 (0.26)	6.77 (0.45)	6.54 (0.36)	7.03 (0.13)	7.16 (0.31)	6.71 (0.29)	6.97 (0.24)	6.78 (0.50)	6.60 (0.25)			

¹MDA = Malondialdehyde; TBARS = Thiobarbituric acid reactive substances.

²NA = Not applicable.

of the PEF treatment settings (number of pulses, power, and frequency) for fresh or frozen turkey breast meat samples ($P \geq 0.05$) as well as when compared to their corresponding control samples ($P \geq 0.05$). This indicated that PEF did not adversely affect the loss of juice during meat cooking. As expected, when compared with the fresh samples (averaged cook loss = 11.9%) frozen samples (averaged cook loss = 14.3%) tended to lose more weight during cooking due to disruption of the meat cells from ice crystal formation ($P < 0.05$). Nevertheless, these values are relatively lower than those reported by other authors ($>20\%$) (Owens and Sams, 2000; Woelfel et al., 2002) when cooked to an internal temperature of 76°C in a convection oven.

Lipid oxidation. Within both the fresh (Table 1) and the frozen (Table 2) PEF-treated samples, there were no differences ($P \geq 0.05$) in lipid oxidation for any of the 3 process factors studied. Moreover, when compared with their corresponding untreated controls, PEF appeared not to enhance nor decrease the lipid oxidation of both fresh and frozen turkey samples ($P \geq 0.05$). For the untreated samples, lipid oxidation appeared to be higher ($P < 0.05$) in fresh samples (5.0 mg MDA/kg) than in frozen samples (2.4 mg MDA/kg), indicating that the frozen state most likely retarded the rate of lipid oxidation. It is well noted in the literature that freezing is not a sufficient method for preventing lipid oxidation as primary lipid oxidation can initiate during frozen storage, which can lead to radical secondary lipid oxidation after thawing (Owen and Lawrie, 1975). However, in this case the duration of freezing was only 48 h which had an inhibitory effect on lipid oxidation regardless of the application of PEF.

Texture analysis. It is widely recognized that meat tenderness is the most significant factor affecting consumer satisfaction, and it can be analyzed through sensory or instrumental analysis or both (Tornberg, 1996). Instrumental texture measurements indicated that there were no differences ($P \geq 0.05$) in the shear force (Newtons) within each PEF process factor for both fresh and frozen samples. It is thought that the PEF treatment applied in the present study may not have been strong enough to induce physical disruption of meat fibers in order to affect texture. There is no agreement in the literature whether PEF treatments enhances or not the tenderization of meat cuts. Results obtained in this study are in agreement with previous studies on PEF-treated beef *semiteminosus* muscles (1.9 kV/cm; 83.6 kJ/kg) (O'Dowd et al. (2013)) and those reported by Arroyo et al. (2015) who observed a tendency but not significant decrease on the shear force values for fresh beef *longissimus thoracis et lumborum* subjected to PEF (1.4 kV/cm; 25 to 50 kJ/kg). Similarly, Faridnia et al. (2014a) reported no effect of PEF (0.2 to 0.6 kV/cm; 0.05 to 34.3 kJ/kg) on the tenderness of beef *longissimus thoracis*. On the contrary, Lopp and Weber (2005) reported a significant decrease (max reduction of 22.5%) on the shear force values for beef *triceps brachii* subjected to a PEF with higher elec-

tric field strength (3.5 kV/cm, 20 Hz, 100 pulses) as well as the tenderness of beef *longissimus lumborum* and *semimembranosus* muscles benefited (max reduction of 19.5% in shear force values) from PEF (0.27 to 0.56 kV/cm; 3.4 to 40.7 kJ/kg) (Bekhit et al., 2014) though it is noteworthy to mention that Bekhit et al. (2014) measured the shear force within 1 wk frozen storage after the PEF treatment.

Instrumental color. Poultry meat color is a critical food quality attribute as the visual appearance of meat ultimately influences the consumer's decision to purchase and the ultimate acceptance of the cooked product upon consumption. Consumers often discriminate against meat cuts that lack a fresh appearance; and meat that becomes discolored is often minced and marketed in a reduced value form. Hunter 'L' 'a' 'b' values for instrumental color in fresh and frozen turkey breast meat, both raw and cooked, are presented in Tables 1 and 2. As can be observed in Table 1, neither of the PEF process parameters significantly affected the color of the fresh turkey breast meat, regardless of it was measured before or after cooking ($P \geq 0.05$). The significant increase on lightness ('L') and yellowness ('b') values observed for cooked samples indicates that as turkey meat is being cooked it moves to a lighter white (discoloration) but more yellow color. Values for fresh, either raw or cooked, turkey breast meat are within those reported in the literature (Fletcher et al., 2000; Tang and Cronin, 2007; Zell et al., 2010). Similar conclusions can be drawn for the frozen samples (Table 2) as neither group of PEF settings studied had an impact on the color, either raw or cooked. In this case, the cooked meat was significantly lighter (higher 'L' value), less red (lower 'a' value), and more yellow (higher 'b' value) than the raw frozen samples. If Hunter 'L' 'a' 'b' color dimensions for untreated raw fresh and frozen samples are compared, only 'a' values differed ($P < 0.05$), indicating that fresh meat had a redder color than frozen meat.

The instrumental analysis experiments were not only designed to compare PEF-treated to untreated turkey meat samples, but also to identify the PEF processing conditions most likely to produce quality differences in samples. Once identified, these conditions would be used in the subsequent sensory analysis to ascertain whether these differences were also observed sensorially. However, when such processing conditions were not evident from the instrumental analysis, the PEF processing conditions representing the highest voltage (3 kV/cm) and largest number of pulses (300) were used to prepare samples for the sensory evaluation.

Sensory evaluation. This is the ultimate test of quality as the success of any new product or the use of novel technologies ultimately depends on the permanent maintenance of desirable sensory characteristics in meat. Although some physical characteristics of meat can be assessed instrumentally, where possible it is better if they are supported by sensory evaluation as this will reflect exactly what will be experienced during

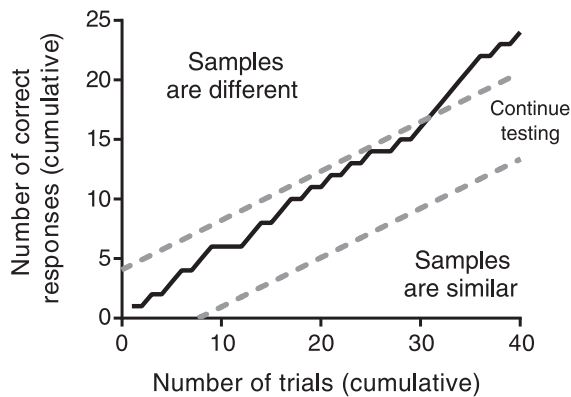


Figure 2. Sensory analysis test plot for texture of control vs. PEF-treated turkey breast meat samples.

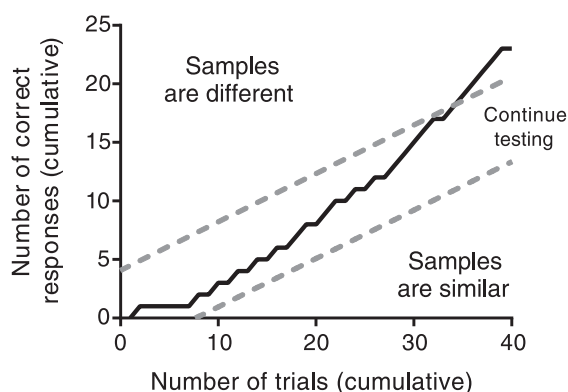


Figure 3. Sensory analysis test plot for odor of control vs. PEF-treated turkey breast meat samples.

consumption. A discrimination triangle test using 40 panelists indicated that they could detect a difference between the PEF-treated turkey samples compared to the control. Panelists attributed the differences to texture and odor ($P < 0.05$) but not color ($P \geq 0.05$). Results for both texture and odor are plotted as a sequential approach in Figures 2 and 3, respectively, indicating that a substantial number of panelists were required before samples could be declared to be different in terms of texture and odor.

Tenderness, color, and odor were also ranked on a hedonic scale. For tenderness, PEF-treated samples on average ranked as ‘neither tough nor tender’ with a mean score of 5.3 (SEM = 0.27) while the control samples were found to be different ($P < 0.05$) and ranked as ‘tender’ with a mean score of 6.19 (SEM = 0.23). The hedonic scale for odor showed that there was a difference ($P < 0.05$) between samples and that the panelists slightly preferred the aroma from the control samples giving the PEF-treated samples an average score of 5.58 (SEM = 0.19) and a score of 6.15 (SEM = 0.20) to the controls. On the contrary, the panelists marked the color as ‘just right’ with no differences found between the PEF-treated and control samples (5.11, SEM = 0.18; 5.29, SEM = 0.19, respectively). On the contrary, a hedonic test performed by Arroyo et al. (2015) with

beef meat indicated that whereas panelists did not detect any differences in odor between PEF-treated and untreated samples, 60% of the panelists scored PEF-treated samples as ‘tender’ (≥ 6.0 points out of 9.0) but only 27.5% did so for untreated samples. These differences may be mainly attributable to the different type of meat as well as the processing conditions used.

CONCLUSION

To date there are few studies examining the effect of PEF processing on muscle food. In this study quality parameters of turkey meat have been assessed after the exposure to different PEF treatments. First, it was demonstrated that PEF treatments did not induce any major adverse side effects on the lipid oxidation of the turkey meat assessed across storage in aerobic conditions. Furthermore, under the PEF conditions examined, none of the factors assessed (voltage, frequency, and pulse number) induced differences in instrumentally measured weight loss, cook loss, lipid oxidation, texture, and color (raw and cooked) either on fresh or frozen samples. However, PEF-treated samples were found to be different from controls in terms of sensorially assessed texture and odor. Nevertheless, it is worth noting that a substantial number of panelists were required before samples could be declared to be different in terms of texture and odor, which suggests that the differences produced by PEF processing are fairly subtle. The subtlety of these differences is also further evident from data presented in Table 1 and 2 when results for PEF-treated samples are compared to their corresponding untreated controls. However, given the importance of meat tenderness and quality, the study does warrant further investigation in order to assess the impact of more severe PEF processing conditions (such as higher electric field strengths) on muscle tenderization as well as the effects of PEF treatment on quality attributes of other types of meat.

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