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Acoustic emission as a tool to assess the changes induced by pulsed electric field in apple tissue

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ABSTRACT

The aim of this work was to analyse the acoustic and mechanical properties of pulsed electric field treated solid-like plant tissue as exemplified by apple fruits. The electrical conductivity of the untreated and PEF treated samples was measured as well. Additionally, an attempt to use the acoustic emission as a tool to assess the electroporation efficiency was done. Subjecting the apple discs to PEF treatment resulted in altered mechanical, electrical and acoustic properties. The compressive force registered at 15% strain was reduced by the PEF application up to 72.7% in comparison to the intact material. The number of acoustic events obtained by the contact method was the most suitable acoustic emission descriptor among other ones to differentiate the PEF treated and intact materials. The results of experiment and especially the PCA point out that the acoustic emission measured by the contact method can be a useful tool to evaluate both the disintegration efficiency and texture changes caused by the PEF application.

1. Introduction

Pulsed electric fields (PEFs) is considered as one of the unconventional methods of food processing, which can be used prior to heat and/or mass-based processes as drying, freezing, osmotic dehydration, extraction etc. (Gachovska, Simpson, Ngadi, & Raghavan, 2009; Martin-Belloso & Sobrino-Lopez, 2011; Puértolas, Cregenzán, Luengo, Álvarez, & Raso, 2013; Soliva-Fortuny, Balasa, Knorr, & Martin-Belloso, 2009; Witrowa-Rajchert, Wiktor, Sledz, & Nowacka, 2014). This emerging technology is based on the application of very short, high voltage pulses to food which is placed between two electrodes. PEF treatment causes the cell membrane disintegration — a phenomenon which is called an electropermeabilization or an electroporation. The plant tissue properties are modified due to the formation of new (or growth of existing) micropores in the cell membrane, which, in turn, causes rupturing of the cellular structure and intracellular content leakage (Bazhal, Lebovka and Vorobiev, 2003; Knorr, Angersbach, Eshtiaghi, Heinz, & Lee, 2001; Ngadi, Bazhal, & Raghaven, 2003; Rastogi, Eshtiaghi, & Knorr, 1999; Saulis, 2010).

The PEF treatment depending on the applied parameters (as electric field intensity, shape and number of pulses, pulse length, frequency) can cause reversible or irreversible electroporation (Ersus, Oztop, McCarthy, & Barrett, 2010; Knorr et al., 2001; Ngadi et al., 2003; Saulis, 2010). The type of the electroporation depends also on the properties of treated food as its cell's size, transmembrane potential of the cell and the thickness of the cell membrane. However, the irreversible electroporation takes place when the transmembrane potential of the cell due to the PEF application will increase above the natural one (Ngadi et al., 2003; Witrowa-Rajchert et al., 2014).

Generally, the effectiveness of PEF treatment is assessed by the determination of the cellular disintegration level. In order to evaluate this parameter, generally the measurement of electrical conductivity or impedance is used. In many cases on the basis of the electrical parameters measurement the cell disintegration indexes are determined (Bazhal, Ngadi, Raghavan and Nguyen, 2003; Ersus et al., 2010; Gachovska et al., 2009; Lebovka, Bazhal, & Vorobiev, 2002; Lebovka, Praporscic, & Vorobiev, 2004a; Wiktor, Witrowa-Rajchert, & Chudoba, 2009). There are also some other indexes which are based on non-electrical measurements. For instance, the electroporation efficiency can be calculated on the basis of the water effective diffusion coefficient (Vorobiev & Lebovka, 2006). Very interesting approach regarding the pulsed electric field treatment efficiency evaluation was presented by Grimi et al. (2010). In this study the technique which was based on the measurement of the acoustic response of the gently taped sample of apple tissue, was developed. The signal which originated from the taped sample was registered and on its basis the stiffness coefficient was calculated. Furthermore, the authors have established the acoustic disintegration index (on the basis of the values of acoustic stiffness coefficient). On the basis of obtained results it was stated that

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acoustically-measured disintegration index is better than the electric conductivity disintegration index because it better characterized and fit the real damage degree of the tissue which was estimated theoretically. Another great advantage of this method is non-destructive character of the measurement. It is also worth to mention that mathematical form of the equation used in this study to establish the acoustic disintegration index was the same as in the case of the electric conductivity disintegration index, i.e. it is the ratio of the two subtractions, so it was easy to calculate. Moreover, in this method similarly to the electrical conductivity disintegration index, it is necessary to establish the totally damaged sample, which can be ambiguous in some cases and there is no standard protocol of treatment in order to obtain the totally disintegrated sample. In many cases the totally disintegrated samples is obtained by freezing and thawing (Asavasanti, Ersus, Ristenpart, Stroeve, & Barrett, 2010; Lebovka, Praporscic, & Vorobiev, 2004b) by double freezing and thawing (Asavasanti, Ristenpart, Stroeve, & Barrett, 2011), by severe PEF treatment (Lebovka, Shynkaryk, & Vorobiev, 2007; Wiktor et al., 2015) or by combination of PEF treatment and freezing–thawing (Grimi et al., 2010).

The texture and acoustic properties, after the colour of the food product, play a significant role in positive or negative perception of the product which refers to the sensory evaluation made by consumers during choosing the food product (Chanvrier, Jakubczyk, Gondek, & Gumy, 2014; Cybulska, Zdunek, & Konstankiewicz, 2011; Giacosa et al., 2015; Kutyła-Olesiuk, Nowacka, Wesoły, & Ciosek, 2013; Śledź, Nowacka, Wiktor, Selke, & Witrowa-Rajchert, 2013). Due to the electroporation phenomenon the application of PEF treatment can cause the changes of textural properties due to the loss of turgor (Grimi, Lebovka, Vorobiev, & Vaxelaire, 2009; Lebovka et al., 2004a). In turn, the acoustic properties are related to product structure and also the mechanical properties (Chanvrier et al., 2014). Acoustic properties are paramount especially in the case of food products which are crunchy or crispy. As aforementioned, it can be stated that despite the importance of acoustic properties regarding the sensory issues, which is quite well understood, the knowledge about the acoustic properties can be also helpful in other domains of food technology — for instance in order to evaluate the efficiency of PEF treatment as it was discussed earlier. However, it should be noticed that there are different methods of acoustic properties measurement. Some of them, as recalled earlier (Grimi et al., 2010) are non-destructive and others allow to record simultaneously the mechanical properties, even though they exhibit destructive character (Gondek, Lewicki, & Ranachowski, 2006).

The objective of this work was to evaluate the effect of PEF treatment, carried out at different parameters, on the mechanical and acoustic properties of apple tissue. Additionally, it can be stated that the determination of acoustic properties was done in order to evaluate the efficiency of the electroporation of plant tissue. What more, the electrical conductivity of the samples was measured co compare the traditional method of electroporation efficiency assessment with the method proposed in current study which is grounded on the acoustic property measurement.

2. Material and methods

2.1. Material

Apples (var. Ligol) originated from the experimental orchard of the Faculty of Biotechnology, Horticulture and Landscape Architecture of Warsaw University of Life Sciences were stored at 4 °C until required. Plant tissue was removed from the storage compartment, washed with potable water before each experiment and left to reach 20 ± 1 °C. The samples were cut in the cylindrical (discs) form (without the peel) with d = 30 mm and h = 5 mm, perpendicular to the main axis of the fruit. Dry matter content was determined according to the AOAC 920.15, 2002 standard.

2.2. Pulsed electric field treatment

Pulsed electric field treatment was carried out in a laboratory scale PEF reactor (ERTEC-RI-1B, ERTEC, Poland) with output voltage up to 30 kV and capacitance of 0.25 μF. The apparatus provided monopolar exponential shaped, pulses. The width of each pulse was equal to 15 μs. In order to minimize the rise of the temperature of the sample the interval between pulses was 2 s. Directly after cutting the cylinders were put into the treatment chamber made of Corian material. The distance between electrodes was 18 mm. Subsequently, the cell was filled with tap water (917.6 μs/cm; 20 ± 1 °C) in order to improve electrical contact between electrodes. The liquid to solid radio was 1:1 (v/v). Tap water was selected as a medium due to the fact that it is more available and suitable (in comparison to the apple juice) in the industrial scale. The cell electrodes were made of stainless-steel. Table 1 presents the parameters of PEF used in the study. Specific energy intake W_s [kJ/kg] was calculated on the basis of following formula (Zhang et al., 2012):

$$W_s = \frac{(V^2Cn)}{2m} \quad (1)$$

where V [V], C [F], n, and m [kg] are the voltage, capacitance of the energy storage capacitor, number of pulses and mass of the sample in the treatment chamber (0.01 kg), respectively. After the PEF treatment the apple discs were withdrawn from the chamber on the sieve and blotted on the filter paper. The temperature increase of the sample after PEF application was not higher than 10.0 °C.

2.3. The electrical conductivity (EC) measurement

Electrical conductivity of the apple disc was measured using an conductometer (CXC-505, Elmetron, Gliwice, Poland) equipped in a self-constructed dual-needle platinum probe (Wiktor et al., 2009). The probe was placed inside the sample by the puncture immediately after the PEF treatment. The frequency of measurement was equal to 100 Hz. The measurements were conducted immediately after PEF application independently for three apple discs, which were blotted with filter paper.

2.4. Mechanical property measurement

The mechanical properties were assessed by the compression test. Measurements were performed on texturometer TA.HDplus (Stable Micro Systems Ltd., United Kingdom; software: Texture Exponent 32, Stable Micro Systems Ltd., Surrey, UK), equipped with the compression plate (d = 75 mm). The following parameters were used: 1.0 mm/s test speed, and 90% of initial sample's height compression. Based on the compression curves the force at 15% strain, peak force (defined as the

Table 1
The parameters of pulsed electric field (PEF) used in the investigation.

Sample code	Electric field intensity (kV/cm)	Number of pulse (−)	Specific energy input (kJ/kg)	Electrical conductivity 10^4 (S/m)
0_0	0	0	0	13 ± 2a
1.85_10	1.85	10	1.13	12.1 ± 0.9a
1.85_50	1.85	50	5.63	14 ± 1a
1.85_100	1.85	100	11.25	11.6 ± 0.6a
3_10	3	10	3	37 ± 3e
3_50	3	50	15	61 ± 3b
3_100	3	100	30	75 ± 4d
5_10	5	10	8	64 ± 5bc
5_50	5	50	40	83 ± 2f
5_100	5	100	80	71 ± 3cd

Different characters indicate different homogenous group (at α = 0.05).