Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Food Engineering 69 (2005) 177–184
JOURNAL OF FOOD ENGINEERING
www.elsevier.com/locate/jfoodeng

Temperature enhanced electroporation under the pulsed electric field treatment of food tissue

Nikolai I. Lebovka [a,b], Iurie Praporscic [a], Sami Ghnimi [a], Eugene Vorobiev [a,*]

[a] Departement de Génie Chimique, Université de Technologie de Compiègne, Centre de Recherche de Royallieu, B.P. 20529-60205 Compiègne Cedex, France
[b] Institute of Biocolloidal Chemistry named after F.D. Ovcharenko, NAS of Ukraine, 42, blvr. Vernadskogo, Kyiv 03142, Ukraine

Received 24 May 2004; accepted 6 August 2004

Abstract

The temperature dependence of effects exerted by pulsed electric fields (PEF) on the electrical conductivity and textural relaxation of potato tissue was investigated in the interval of 22–50 °C. The pronounced decrease of the characteristic electrical damage time τ with increase of both temperature T and electric field strength E was observed. Textural data reveal the essential temperature influence on tissue softening after the PEF treatment. The investigation of thermally induced damage at temperatures within 45–60 °C shows that effects observed below 50 °C are not related to any noticeable irreversible damage of the cellular membranes and reflect only effect of structural transitions in membranes on electroporation. It is of practical importance that PEF treatment under the mild thermal conditions (below 50 °C) allows to reach high tissue disintegration degree at moderate electric field strength (below 100 V/cm).

Keywords: Electroporation; Temperature dependence; Pulsed electric field; Texture; Characteristic damage time; Potato

1. Introduction

It is known for decades that pulsed electric fields (PEF) can cause electroporation or complete damage of the cell membranes in biological objects (Weaver & Chizmadzhev, 1996; Zimmermann, 1986). Recently this interesting phenomenon allowed to develop different promising modern processing methods for food industry. For example, PEF application for microbial inactivation, juice extraction, dehydration and drying were reported in (Barbosa-Canovas, Gongora-Nieto, Pothakamury, & Swanson, 1998; Bajgai & Hashinaga, 2001; Barsotti & Cheftel, 1998; Bazhal, Lebovka, & Vorobiev, 2001; Bazhal & Vorobiev, 2000; Taiwo, Angersbach, & Knorr, 2002; Vorobiev, Bazhal, & Lebovka, 2001; Wouters & Smelt, 1997). PEF treatment destroys cell membranes, removes the cellular turgor component of the texture and exert an estimable influence on the visco-elastic properties of plant tissue (Fincan & Dejmek, 2003; Lebovka, Praporscic, & Vorobiev, 2003). The combined pressure-PEF treatment allows to enhance the solid–liquid expression of different biological tissues and to increase the juice yield (Vorobiev, Jemai, Bouzrara, Lebovka, & Bazhal, 2004). The effective plant tissue disintegration under the PEF treatment can be achieved at moderate electric fields of 500–1000 V/cm, short treatment time within 10^{-4}–10^{-2} s and room temperature (Lebovka, Bazhal, & Vorobiev, 2001, 2002). This method can be a good alternative to the traditional thermal methods of plant tissue treatment, which induce losses of product quality, including partial disintegration of pigments, vitamins and flavouring agents.

* Corresponding author. Tel.: +33 3 4423 5273; fax: +33 3 4423 1980.
E-mail address: eugene.vorobiev@utc.fr (E. Vorobiev).

0260-8774/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jfoodeng.2004.08.037

Nomenclature

d	sample diameter (mm)
E	PEF intensity (V/cm)
E_0	empirical parameter (V/cm)
F	force (N)
h	sample height (mm)
n	number of pulses
N	number of trains
R	universal gas constant, 8.314 ($\mathrm{J\,K^{-1}\,mol^{-1}}$)
t	time (s)
t_i	pulse duration (μs)
t_∞	effective relaxation time (s)
t_{PEF}	time of PEF treatment (s)
Δt	pulse repetition time (ms)
Δt_{t}	time pause between trains (s)
T	temperature (°C)
u_{m}	transmembrane potential (V)
u_0	voltage parameter (V)
ΔU	activation energy (kJ/mol)
Z	electrical conductivity disintegration index

Subscripts

E	electrical
T	thermal

Greeks

ρ	correlation coefficient
σ	electrical conductivity ($\mathrm{S\,m^{-1}}$)
τ	characteristic damage time (s)
τ_∞	limiting characteristic damage time (s)

Abbreviation

PEF	pulsed electric fields

However, the application of the PEF-treatment alone can be inefficient if any significant modifications of the plant structure, like softening of the cell walls or violation of their integrity, are desirable. Additional softening of the plant tissues (carrots, potatoes and apples) can be observed in combined mode of PEF treatment at room temperature and mild thermal treatment (Lebovka, Praporscic, & Vorobiev, 2004a, 2004b). It was shown that thermal softening at mild heating is associated mainly with structural changes in the cell walls, and, to the less extent, with damage of membranes. The mild thermal and ohmic heatings allow to improve mechanical juice extraction from plant tissues (Lima & Sastry, 1999; Wang & Sastry, 2000, 2002; Zhong & Lima, 2003).

In previous investigations practically all the PEF treatment experiments were done at room temperature (Bazhal, Lebovka, & Vorobiev, 2003; Fincan, DeVito, & Dejmek, 2004; Fincan & Dejmek, 2002, 2003; Lebovka, Bazhal, & Vorobiev, 2000, 2001, 2002; Vorobiev et al., 2004) and the effect of temperature on the PEF-induced damage phenomena of in food tissues, practically, was not studied yet. Nevertheless, the electroporation of membrane is sensible to the temperature (Zimmermann, 1986) and temperature can influence PEF-induced damage in a plant tissue. The objective of this work is to study temperature effect on the efficiency of PEF treatment of a plant tissue.

2. Materials and methods

As a representative object for investigation, a potato tissue was chosen. Potatoes (Milva) of good and uniform quality were purchased at the local supermarket and stored at 4 °C until required. The moisture content was within 83–85%.

We checked the quality of potatoes by carrying out the stress relaxation test on fresh potatoes each time we tested samples, to ensure that the texture did not change. The samples were in the form of cylinders having diameter $d = 26$ mm, height $h = 10$ mm in PEF experiments and $d = 10$ mm, $h = 10$ mm in textural experiments. After preparation of the potato cylinders, they were soaked into fresh potato juice prepared from the same plant tissue at 20 °C. Fresh juice was chosen as a natural medium in order to reduce the degradation of the sample.

A scheme of experimental setup is presented in Fig. 1. The PEF treatment chamber consists of polypropylene cylindrical glass with the inner diameter 26 mm and an electrode at the bottom. The treatment chamber, filled with fresh potato juice, was placed to the water thermo-

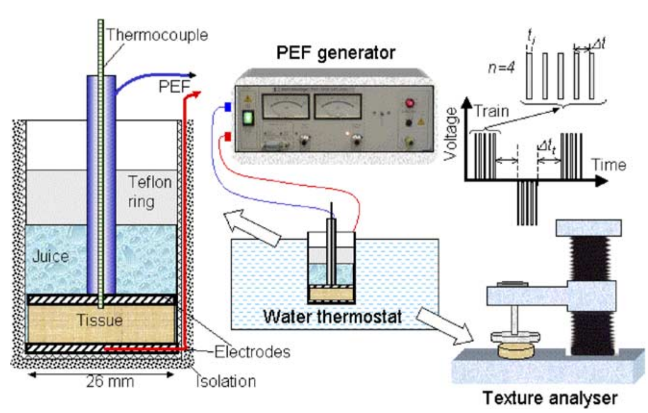

Fig. 1. A scheme of the experimental setup. See text for details.