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Paper Title: BEETROOT JUICE EXTRACTION USING PULSED ELECTRIC FIELD COMBINED WITH MECHANICAL PRESSING

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BEETROOT JUICE EXTRACTION USING PULSED ELECTRIC FIELD COMBINED WITH MECHANICAL PRESSING

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Abstract: In this paper, simultaneous mechanical pressing and PEF treatment for beetroot juice extraction was experimentally investigated and discussed. The experiments were carried out using the laboratory PEF treatment system, operated at the electric field strength in the range from 2.5 to 5 kV/cm, the pulse duration of about 100 μs, the pulse repetition time of about 10 ms, the pulse frequency of about 1 Hz, the PEF treatment time in the range from 10 – 20 min, the constant pressure of about 3 bar, and the total time of mechanical expression up to 5 min for with and without PEF treatment. In absence of the PEF treatment, the final juice yield for beetroot was not depended on the PEF treatment time. It was shown that the PEF treatment before pressing results in higher juice yield of beetroot than only pressing. Increased in the electric field strength resulted in increasing the juice yield of beetroot in narrow range. In case of pressing without PEF treatment, the average juice yield of beetroot was found up to about 31 %. The maximum juice yield of beetroot was found up to 71 % for the electric field strength of 3.75 kV/cm at the PEF treatment time of 15 min in pressing with PEF treatment. This results evidence that PEF enhanced expression is promising for production of higher quality juices in food industry.

Keywords: Pulsed electric field, Extraction, Juice, Beetroot.

1. INTRODUCTION

The pulsed electric field (PEF) technology has been successfully demonstrated for the preservation of food products quality such as juices, milk, yogurt, soups, and liquid eggs. The PEF application provides a possibility of low electric power input regulation and might result in effective permeabilization of cellular membranes without significant temperature elevation [1].

Recently, the benefits of the PEF technology were demonstrated for juice extraction and nutritive molecules from vegetables e.g. β-carotene, sugar, pigments [2]. The PEF of moderate high intensity electric field between 500 and 1000 V/cm and short duration from 10^{-4} to 10^{-12} s allows permeabilization of cell membranes and, therefore, facilitates expression of juice and it components. There are numerous studied for cellular juice extracting from carrots, apples, white grapes and sugar beets [2 ÷ 11]. The obtained results are especially promising for combined solid-to-liquid expression and PEF treatment. However, the effectiveness of the PEF treatment depends largely upon the type of biological material and initial condition of cellular structure of vegetables or foods. All these factors affect considerably the local electrical conductivity or resistivity of micro-structure elements and cause more or less an effective treatment of the whole press-cake. Therefore, the elucidation of combined effect of pressure and PEF treatment is needed to optimize this promising process.

In this paper, simultaneous mechanical pressing and PEF treatment for beetroot juice extraction was experimentally investigated and discussed. The laboratory PEF treatment system was developed in this work. All experiments were operated at the electric field strength in the range from 2.5 to 5 kV/cm, the pulse duration of about 100 μs, the pulse repetition time of about 10 ms, the pulse frequency of about 1 Hz, the PEF treatment time in the range from 10 – 20 min, the constant pressure of about 3 bar, and the total time of mechanical expression up to 5 min for with and without PEF treatment.

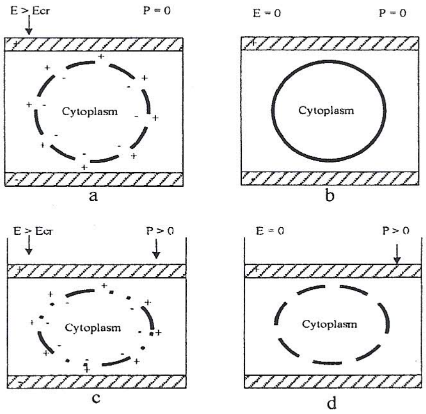

Fig. 1. Mechanism of electroporation (a, b), without mechanical pressure assistance; (c, d), with mechanical pressure assistance.

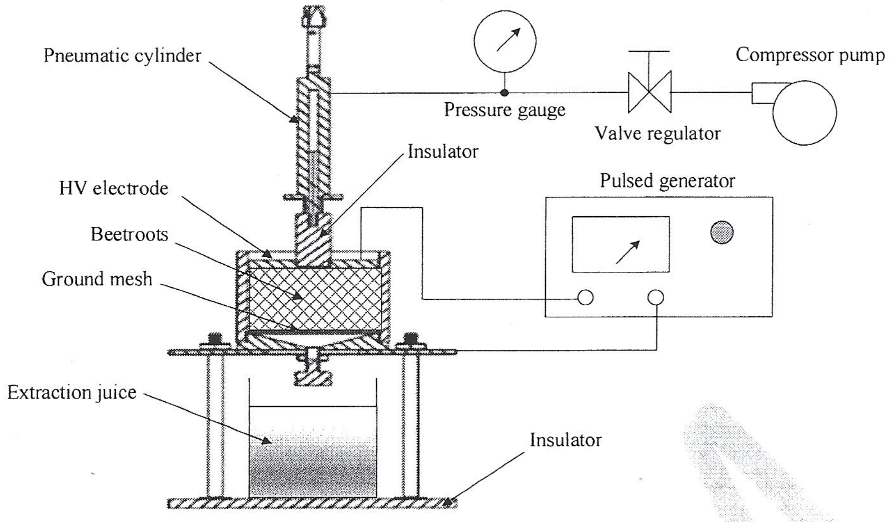

Fig. 2. Experimental apparatus.

2. BACKGROUND ON THE PEF TREATMENT OF BIOLOGICAL TISSUE

Recently, PEF technology is successfully used in biomedicine, cell biology and biotechnology [1]. The PEF treatment as a new emerging non-thermal technology was also applied to liquid foods for inactivation of microorganisms and denaturation of enzymes [9]. The cell membrane exposed to high intensity electric field can be temporarily destabilized or irreversibly ruptured. The conception of membrane electroporation was proposed as a result of its dielectric breakdown [2]. Direct evidence of pore formation does not exist, such as imaging at the membrane level. The existing knowledge is phenomenological and is based on measurements of electrical current through planar bilayer membranes under external electric field. These measurements show the dramatic increase of electrical conductivity or permeability of cellular tissue subjected to electric field pulses. The observed phenomenon is called electroper meabilization of membrane and hypothetically explained by its electroporation.

Fig. 1 shows a simple model of cell behavior under electric field. The cell membrane is presented as a capacitor filled with a material of a low dielectric permittivity in this model. The typical value of physiological potential difference of the cell e_{ph} is about of 0.1 V in absence the electric field [9]. The charging process and the electrical polarization of membrane are induced when the biological tissue is exposed to an external electric field. The free charges accumulate on both inside and outside of membrane surfaces, which increases the potential difference e_m ,named transmembrane potential difference, between the membrane surfaces. The resulting transmembrane potential difference is given by

$$e_m = g d_c E \cos\theta \pm e_{ph} \qquad (1)$$

where g is the geometrical coefficient (g = 0.75 for the spherical cell and g = 1 for cubical cell), E is the strength of external electric field, θ is the polar angle between the direction of external field strength and the induced membrane field strength.

The electrical pressure exerted on the cellular membrane is given by

$$P_{el} = \frac{\varepsilon_m e_m^2}{2 d_m^2} \qquad (2)$$

where ε_m is the dielectric permittivity of the cellular membrane, d_m is the thickness of the membrane (d_m~5 nm).

3. DETAILS EXPERIMENTAL

3.1. Experimental Setup

Fig. 2 shows the schematic diagram of the experimental apparatus. It consisted of the PEF chamber, the pulsed generator, the pressure gauge, the valve regulator, and the compressor pump. The PEF chamber was developed in this study (Fig. 3). It consisted of a polypropylene cylinder with inner diameter of 13 cm and height of 20 cm, the mobile electrode (made of stainless steel 316L), the stationary mesh electrode (made of stainless steel 316L) with circular holes of 0.1 mm × 0.1 mm, and the pneumatic cylinder. The distance between the mobile and stationary electrodes was about 4 cm. The cylinder compartment was initially filled with split beetroot and then tightly closed from both sides with mobile and stationary electrodes. The initial sample weight was about 200 g. The PEF chamber was applied a high voltage pulse generator, typically from 15 to 20 kV, which provided positive unipolar pulses of an exponential decay shape as shown in Fig. 4.

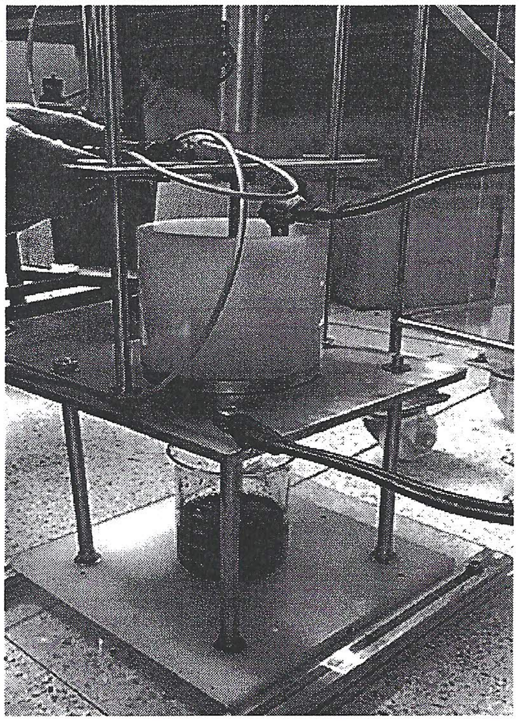

Fig. 3 Protoype of developed PEF chamber

The pulsed generator was developed in this study as shown in Fig. 5. It consists of a high-voltage power source, an energy storage capacitor bank, a charging current limiting resistor, a switch to discharge energy from the capacitor across the food and a treatment chamber. Energy from the power source was stored in the capacitor bank and was discharged through the PEF treatment chamber to generate an electric field in the food material. The maximum voltage across the capacitor is equal to the voltage across the generator. The capacitor bank is charged by a direct current power source obtained from amplified and rectified regular alternative current main source. An electrical discharge switch is used to discharge energy (instantaneously in millionth of a second) stored in the capacitor storage bank across the food held in the treatment chamber.

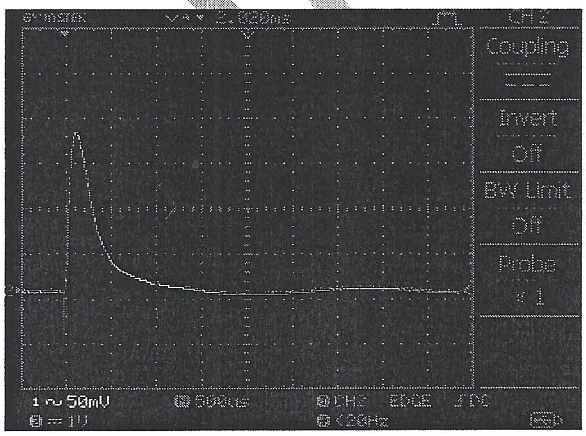

Fig. 4. Unipolar exponential decaying.

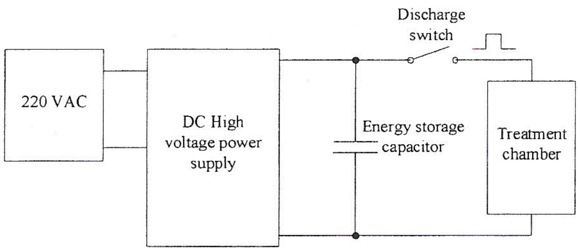

Fig. 5. Schematic diagram of the developed pulsed generator.

3.2. Methods

All experiments were operated at the electric field strength in the range from 2.5 to 5 kV/cm, the pulse duration of about 100 μs, the pulse repetition time of about 10 ms, the pulse frequency of about 1 Hz, the PEF treatment time in the range from 10 – 20 min, the constant pressure of about 3 bar, and the total time of mechanical expression up to 5 min. A pressure value of 3 bar was accepted as the most efficient for exhibition of the effect of simultaneous pressing and PEF treatment. The experiments were repeated at least five times in this study. We analyzed the mass of the beetroot juice for each portion. The mass of the expressed beetroot juice was measured with the electronic scales (Sartorius model BSA2201-CW). The juice yield of the relative mass losses (*Y*) was calculated using the following equation:

$$Y = \frac{m}{m_i} \times 100 \tag{3}$$

where m is the mass of the expressed beetroot juice and m_i is the initial mass of beetroot before pressing. In this study, total soluble solid of the beetroot juice was measured by the Refractometer (Atago model MASTER-M) and Color meter (Hunter Lab model Color Flex Standards Box) was used to measure the CIE colour value of the beetroot juice.

4. RESULTS AND DISCUSSION

Table 1 shows the experimental data on expression kinetics of juice from beetroot in pressing without PEF treatment and with PEF treatment for PEF treatment time of 10, 15 and 20 min, the electric field strength of 2.5, 3.75 and 5 kV/cm and the constant pressure of 3 bar. In absence of the PEF treatment, the final juice yield for beetroot was not depended on the PEF treatment time. It was shown that the PEF treatment before pressing results in highest juice yield of beetroot. Increased in the electric field strength resulted in increasing the juice yield of beetroot. As shown in Fig. 6, it was expected that the PEF treatment provokes an electropermeabilization of cells, increases the total juice yield and accelerates. As shown in Table 1, the maximum juice yield of beetroot was found up to 71

% for the electric field strength of 3.75 kV/cm at the PEF treatment time of 15 min in pressing with PEF treatment. In case of pressing without PEF treatment, the average juice yield of beetroot was found up to about 31 %. Table 2 was also showed the CIE colour value, pH and °Brix of beetroot juice with and without PEF treatment.

Table 1: Experimental data on expression kinetics of juice from beetroot in pressing without PEF treatment and with PEF treatment.

Electric field strength (kV/cm)	PEF treatment time (min)	Without PEF treatment (mL)	With PEF treatment (mL)
	10	262.37	321.57
2.5	15	252.65	323.67
	20	253.47	324.77
	10	256.64	329.17
3.75	15	257.50	343.67
	20	259.20	333.14
	10	258.50	327.17
5	15	258.07	325.57
	20	257.94	327.30

(a) Before PEF treatment

(b) After PEF treatment

Fig. 6. Beetroot before and after PEF treatment.

CONCLUSIONS

A simultaneous mechanical pressing PEF treatment for extracting beetroot juice has been experimentally investigated and discussed in this paper. The laboratory PEF treatment system was developed in this study. It consisted of the PEF chamber, the pulsed generator, the pressure gauge, the valve regulator, and the compressor pump. The PEF chamber used in this work was consisted of a polypropylene cylinder with inner diameter of 13 cm and height of 20 mm, the mobile electrode, stainless steel 316L, the stationary mesh electrode, stainless steel 316L, with circular holes of 0.1 mm × 0.1 mm, and the pneumatic cylinder. The distance between the mobile and stationary electrodes was about 4 cm. In this experiments were operated at the electric field strength E in the range from 2.5 to 5 kV/cm, the pulse duration of about 100 μs, the pulse repetition time of about 10 ms, the pulse frequency of about 1 Hz, the PEF treatment time in the range from 10 – 20 min, the constant pressure of about 3 bar, and the total time of mechanical expression up to 5 min. It was shown that the PEF treatment before pressing results in highest juice yield of beetroot. Increased in the electric field strength resulted in increasing the juice yield of beetroot. The maximum juice yield of beetroot was found up to 71 % for the electric field strength of 3.75 kV/cm at the PEF treatment time of 15 min in pressing with PEF treatment. In case of pressing without PEF treatment, the average juice yield of beetroot was found up to about 31 %.

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Table 2: CIE colour value, pH and °Brix of beetroot juice with and without PEF treatment

Electric field strength (kV/cm)	PEF treatment time (min)	CIE colour value						pH		°Brix	
		L^*		a^*		b^*					
		without PEF treatment	with PEF treatment	without PEF treatment	with PEF treatment	without PEF treatment	with PEF treatment	without PEF treatment	with PEF treatment	without PEF treatment	with PEF treatment
2.5	10	3.98	1.96	6.62	2.47	1.96	0.16	5.28	5.22	0	2.2
	15	4.36	1.38	7.17	1.49	2.15	0.34	5.12	5.17	0.1	2.1
	20	3.04	1.65	5.14	2.26	1.64	0.56	5.24	5.22	0.2	2.2
3.7.5	10	3.51	2.08	6.15	1.78	1.46	0.92	5.09	5.10	0.3	2.5
	15	2.54	1.89	3.03	1.57	1.00	0.59	5.27	5.19	0.3	3.2
	20	3.95	1.82	7.10	2.19	2.14	1.97	5.11	5.10	0.2	3.0
5.0	10	2.15	1.53	3.59	2.20	0.73	0.39	5.28	5.25	0.3	2.9
	15	2.78	1.79	4.00	2.89	0.58	0.58	5.17	5.29	0.3	3.0
	20	2.37	1.86	4.25	2.92	0.90	0.69	5.17	5.07	0.3	3.2

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