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Applications of electricity and specifically pulsed electric fields in food processing: Historical backgrounds

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ABSTRACT

Starting from two-three decades ago pulsed the electric field (PEF) treatment became very popular in a food industry. Many important effects and mechanisms related with impact of PEF on bio-, food or agricultural products have been discovered and elucidated for this period. Concept of electroporation has been fundamentally developed. The positive effects of PEE-assisted processing for inactivation of microorganisms, extraction, pressing, osmotic dehydration, drying, and freezing have been observed. Recent development and success of PEF applications has been also supported by the growing number of commercially available PEF generators with different characteristics, power and particular protocols. In the current paper, research works and applications of electricity and specifically pulsed electric fields in food processing over the period until the middle of the 1990s are summarized. A historical overview is presented in two steps devoted to: (a) the early studies on impact of electricity on growth, vegetation and germination and treatment of food by electricity before the 1940s and (b) the development of concept of selective electroplasmolysis and the first attempts to use the electricity and specifically the PEF treatment in food industry in the period between the 1940s ;and 1990s.

Industrial relevance: During the long history of testing of electricity and specifically the PEF treatment in industrial relevant processing the serious problems and obstacles were revealed. Many pilot scale constructions were proposed and tested during the period between the 1940s and until the middle of the 1990s by different investigators from West Germany and USSR (Ukraine and Moldova). However, finally that technology was not industrialised due to the technical difficulties, the absence of necessary financial support and the lack of knowledge about basic mechanisms responsible for the impact of PEF. This historical experience can be very instructive for the development of modern applications of PEF technology in food industry.

Contents

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1. Introduction

The term of electricity is based on the Latin word electricus for "amber" and it was introduced at the beginning of the 17th century by the British scientist Gilbert made for description of the effects of attraction produced by rubbing amber (Gilbert, 1600). Impact of electricity on biological objects, their growth, vegetation and germination continuously attracts great attention over a period of many centuries. More than a hundred years ago the first applications of great attention over a period of many centuries for warming up the foods and for killing of microbes were also started. During this period the interesting, intriguing, and unclear phenomena were observed in the studies on treatment of biological materials with application of the different kinds of electricity (static electricity, continuous or alternating electrical currents and pulsed electricity). In the middle of the 20th century the pulsed electric field treatment (PEF) for processing of food and agricultural products started to be applied. Revolutionary role in the field was invoked by the fundamental discovery of the phenomenon electroporation and understanding of the mechanisms of electrical breakdown of membranes.

Note that the first experimental report on electroporation had appeared probably in the 1958th (Stampfli, 1958) and practically at the same time the different experimental groups (Doevenspeck, 1960; B. R. Lazarenko & Reshetko, 1968a; A Ya. Zagorul'ko, 1958a) had started the first applications of PEF for treatment of food products. The first experiments with the PEF applications for killing of microorganisms were reported in the 1960^s (Hamilton & Sale, 1967; Sale & Hamilton, 1967). Later on, in the 1970^s the fundamental experiments on electrical breakdown of biological membranes were performed (Neumann & Rosenheck, 1972; Zimmermann, Schulz, & Pilwat, 1973) and the membrane electroporation concept was theoretically grounded (for a review, see Weaver & Chizmadzhev, 1996).

Starting from the 1990^s the application of PEF in processing of food and agricultural products becomes more and more popular (Barbosa-Canovas, Gongora-Nieto, Pothakamury, & Swanson, 1998; Gulyi et al., 1994; Knorr, Geulen, Grahl, & Sitzmann, 1994a, 1994b). Nowadays, the PEF is considered as a very promising non-thermal treatment that allows avoidance of undesirable changes in foods typical for other techniques, such as thermal, chemical and enzymatic ones (Raso & Heinz, 2006; Vorobiev & Lebovka, 2008). Among numerous examples of PEF applications for inactivation of microorganisms, intensification of separation, extraction, pressing, freezing, diffusion and drying may be mark out. PEF-assisted technologies are attractive for different applications in food, medicine, pharmacy, cosmetics and biofuel industries. Many reviews on different applications of PEF treatment in food industry have been in the last decades (see, for example Barbosa-Canovas & Altunakar, 2006; Donsi, Ferrari, & Pataro, 2010; Jaeger, Balasa, & Knorr, 2008; Knorr, Engel, Vogel, Kochte-Clemens, & Eisenbrand, 2008; Lebovka & Vorobiev, 2010).

This review analyzes the history of applications of the electricity, electroporation and pulsed electric field in food industry for a period until the middle of the 1990^s.

2. Early studies on impact of electricity on objects of biological origin before 1940th

2.1. Impact of electricity on growth, vegetation and germination

The earliest work on application of electricity in relation to biological objects was probably done by Maimbray (Edinburgh) in the 1746th. He observed stimulating role of electricity upon the growth and flowering of myrtle plants (see, e.g. Nollet, 1749). In the 1747th Abbot Nollet (1700–1770, he was born in Pimprez near the Compiegne, France) discovered the accelerated rates of germination and overall growth when cultivated under charged electrodes (Nollet, 1749). He also applied electrostatic machines and Leyden jars for electrotherapy. The successful experiments of Maimbray and Nollet on the influence of electricity on vegetation were confirmed approximately at the same time by Jallabert (Geneva), Boze (Wittemberg), Abbe Menon(Angers), Nuneberg (Stuttgard), Beccaria (Turin) and many other investigators (for a review, see Solly, 1845). In the 1783th, Abbot Bertholon described a special "electrovegetometer," for spraying of electrified water over the growing crops (Bertholon de Saint-Lazare, 1783). In the 1779th, Comte de Lacepede described some experiments on the effects of electricity on grown of vegetables and germination of seeds (De Lacepede, 1781). The very important was the discovery of bioelectricity by Luigi Galvani. His book "On the strength of electricity in the muscular movement" was issued in the 1791th (Galvani, 1791).

Later on an increase in the yield was observed for electrically pretreated potatoes in a galvanic cell (Ross, 1844). The comprehensive review of the previous works on the effects of electricity on the growth and yield of crops was issued in the 1845th (Solly, 1845). In the 1884th Bailey had discussed the effects of electrification on plant growing, germination of seeds and ripening of fruits (Bailey, 1894). He noted that direct application of a mild and steady electrical current may result in more rapid growth and earlier maturity of the treated plant. The nature of observed electrification was explained by chemical effects in hastening the metabolism of the seed or fruit contents. In the 1885th, the stimulation of the growth (up to 70%) of crops such as potatoes, carrots, and celery by the electrical discharge treatment was observed (Lemström, 1904a, 1904b). In the 1898th, in the book "Electro-horticulture", the different aspects of electricity application to the stalks and plant roots as well as effects of electricity upon vegetation were discussed (Hull, 1898). In the 1889th, in experiments at the Botanical Garden of Kiev, a successful example of electricity application in an agriculture was demonstrated (Spechnew, 1889).

Action of electric currents upon a growth of seeds and plants was discussed in the 1892th (Leicester, 1892). The influence of atmospheric electrical potential on growth was studied in the 1904th (Monahan, 1904). The experiments were done by charging of air glass case to a potential of about fifty volts. The marked stimulation effects of few minute sparks on plant growth and germination of seeds have observed in the 1904th (Stone, 1904). It was stated that electricity undoubtedly affects a protoplasm of plant and stimulates activity the certain metabolic processes.

At beginning of the 20th century the mechanisms of electricity influence on plants were discussed in the book "Electricity in agriculture and horticulture" (Lemström, 1904a, 1904b) and in the book "Growing crops and plants by electricity. Explaining what has been done on a practical scale" (Dudgeon, 1912). For example, a remarkable development in a vegetation observed in the Polar regions was explained by the effects of atmospheric electricity (Lemström, 1904a, 1904b). The beneficial effects of current treatment on germination and plant growth were also demonstrated (Stone, 1904). A comprehensive review on application of electrical conductivity measurements for testing of plant physiology was issued in the 1914th (Stiles & Jörgensen, 1914).

Application of the electrical discharge allowed acceleration the ripening of cucumber fruits with a 17% increase in yield (Newman, 1911; Priestley, 1907). In the 1911th, Olsson patented an irrigation systems that use electrified water for sprinkling fields (Olsson, 1910). He stated observed destroying the various harmful insects and other organisms by application of his procedure. His system was used in parks of the city of Buenos Aires. The term "electroculture" was proposed to refer the effects of electricity on the growth and yield of crops (Briggs, Campbell, Heald, & Flint, 1926). In the 1927th, a book «Electroculture», devoted for a method of applying atmospheric electricity to the fertilization of plants was issued (Christofleau, 1927).

The different original works and reviews on the phenomena of "electroculture" were issued later on (Black, Forsyth, Fensom, & Ross, 1971; Diprose, Benson, & Willis, 1984; Edwards, 1976; Giri, Mirchandani, & Subrahmanyan, 2013; Krueger, Strubbe, Yost, & Reed, 1978; Sidaway, 1975). The effects of various electric fields (electrostatic fields, microwave radiation, electrical discharges, electric shocks and