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Kitchen cooking by electroporation

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Abstract: Recently, modern non-heating-based food processing alternatives have emerged. The pulsed electric field (PEF) technology is an example, which does not require high temperatures and, in principle, preserves both the nutritional and functional characteristics of the food while possibly improving the taste. Nevertheless, using this technology in kitchen conditions is still a challenge. Thus, the main aim of this work was the development of a kitchen cooking device that uses pure pulse electroporation (without thermal effects). A device powered by a common electrical network was designed. The voltage applied to the electrodes is approximately 150 V. At a food thickness of 3 mm, an intensity of 500 V·cm^{-1} was achieved, which was sufficient for the electroporation of typical vegetables. Depending on the specific food being treated, the device repeats the pulses until the required degree of the PEF treatment is reached. Preparing a larger amount of food at one time would require great instant power from the device. In order to load the device with less current, the large working area of the electrodes was divided into nine segments. The food is gradually prepared segment by segment. The function of the device is controlled via an electronic programmable control unit. The electroporation of the processed material was achieved with a functional prototype of the designed device, but with some limitations that have to be respected in further development.

Keywords: electroporation; food treatment; kitchen appliances; PEF

Electric or gas stoves that combine cookers and ovens are currently used in kitchens. Electric ovens began to be widely used when the practical application of electricity improved in the late 1920s (Universal Appliance and Kitchen Center 2018). From the late 1970s, microwave ovens increasingly became a standard feature of residential kitchens (Liegey 2002). All of these solutions use heat treatments to process the food.

Nevertheless, as a result of higher consumer demands for foods with a higher health content and a "fresh-like" taste, modern alternatives to conventional cooking methods are emerging (Toepfl et al. 2014). Improving the taste of the food is the main purpose of cooking, which is usually achieved by adapting its texture, e.g. softer or juicier, to such a state that is savoury for a customer (Blahovec et al. 2015). A pulsed electric field (PEF) is a relatively new technique, which does not require high temperatures and, in principle, preserves the nutritional, sensory, and functional characteristics of the food (Cortese et al. 2011) while possibly improving the taste of the food. Dunn pointed out this in 1996, stating that the advantage of PEF processing is that it can be applied at moderate temperatures at which no appreciable thermal damage occurs, and the original food taste, colour, texture, and functionality can be retained (Dunn 1996). New functionality possibilities in research and industrial applications are provided by PEF technologies. The principle of the PEF technology is that a high-voltage, short-duration electric pulse is applied to the material placed between two electrodes. This creates a strong electric field. The resulting electroporation of the cell membranes is either reversible or irreversible (depending on the pulse protocol). This allows the development

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and application of innovative treatments (Vitave GmbH 2021). The electroporation of plant products has found applications in industrial processing. According to Vorobiev and Lebovka (2020), small-scale electroporation devices and large-scale PEF devices exist. While small-scale devices have been designed to produce the precise PEF protocols to study the electroporation of cells, bacteria, fungi or yeasts, large-scale PEF generators have a wide range of uses. The first commercial PEF devices were used to pasteurise liquids such as milk, fruit juices, etc. (Dunn 1996). Furthermore, these large devices are used in the production of olive oil (OptiCept 2021), to accelerate the drying process (Elea 2021), in food extraction, inactivation, and sterilisation applications (Energy Pulse Systems 2021; WekTec 2021), in the microbial inactivation of liquids (Pulsemaster 2021), or in the production of biogases (OptiCept 2021). In most cases, these are large industrial devices with a capacity of tens to thousands of litres per hour or tens of tonnes per hour. However, Vorobiev and Lebovka (2020) also pointed out the possibility of using this technology in the home environment, where time also plays a significant role. The key issue here is to develop a table device where electroporation is performed in real time and the products are consumed immediately. The Nutripulse® E-cooker (Patent EU WO 2016008868 A1; Van Oord and Roelofs 2016) probably comes closest to these requirements, manufactured by the IXL BV company (Netherland), which can be used for the fast preparation of food products (fish, meat, or vegetables). The E-cooker partly operate as a PEF stimulated cooker at low temperatures and as PEF-thermally simulated electroporation upon heating above 40–50 °C and opens new opportunities for fresh food preparation (Goettsch and Roelofs 2014). Thus, this technology is still not a direct application of the PEF, but it is an improvement on the existing heating-based technologies. The full application of PEF technologies in kitchen conditions was first proposed by Blahovec et al. (2017). In this paper, the motivations and limits of such a solution were also defined.

It is clear from a previous literature review that technology based on the direct application of PEF in kitchen conditions ("on the table") is still lacking. The aim of this study is the development of a small kitchen cooking device that uses a pure electroporation process. Electroporation must, therefore, be achieved in compliance with strict safety rules using the electric network's relatively low voltage of 230 V.

MATERIAL AND METHODS

The function of the whole device was tested during the treatment of carrots. For this purpose, the carrots were cut into 9 rings approximately 3 mm thick. These rings were then inserted on the individual pulse electrode segments. The mechanical part of the device was then closed. The device was then switched on with a button and the pulsing took place for about 30 seconds.

The electroporation of vegetables needs an electric field density of several hundred volts per 1 cm (see Figure 1 in Blahovec et al. 2017). At the same time, processed cellular products have to be particularly sliced to form the necessary electric field.

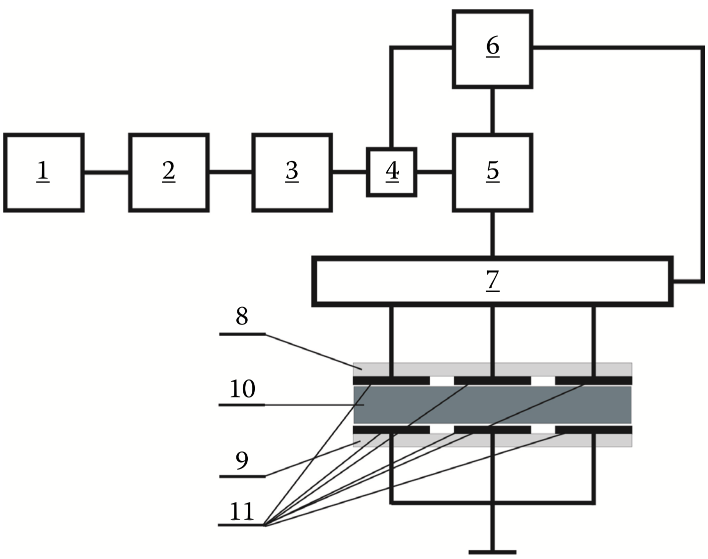

Figure 1. Schematic drawing of a functional sample of a kitchen PEF cooker

1 – transformer; 2 – rectifier module; 3 – capacitor bank; 4 – current measurement; 5 – AC generator; 6 – control unit; 7 – relay field; 8 and 9 – contact (pulsing) electrodes; 10 – processed food; 11 – pulse electrode segments; AC – alternating current

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The block diagram of the proposed technical solution is shown in Figure 1.

For this purpose, a device was developed in two parts. The first part (Figure 1, positions 1–7) is supplied by the standard 230 V electrical network that is available in every kitchen. The second part is a special applicator (Figure 1, positions 8–11). The initial voltage in the first part is firstly reduced and isolated from the grid by the transformer. The voltage coming from the transformer is then rectified by the rectifier module so that it can be used to charge the capacitor bank. An H-bridge was used to convert the direct current (DC) voltage from the capacitor bank to an alternating current (AC) 18 kHz modified square wave (Vorobiev and Lebovka 2020), which was then used to treat the food. Each AC pulse length was 11 ms and the average specific energy input of one pulse was 1.7 kJ·kg^{-1}. The control unit controls the operation of the AC voltage generator. Based on the programmed algorithm and the reception of the signal from the current probe, the control unit enables the pulsing and determines the number of pulse repetitions to the individual segment, and further controls the ± switching and switches the current via the relay field to the individual segments of the contact working electrode in the applicator. The entire pulsing process is controlled by a system of buttons. The pulsing voltage is fed to the applicator by a cable. The operator can monitor the entire pulsing process on the information display, which also gives the operating instructions. A practical design of the functional PEF kitchen device is shown in Figure 2. During pulsing, the impedance of the pulsed material decreases due to the disruption of the cell membranes (Blahovec 2015; Vorobiev and Lebovka 2020). As a result of the reduction in the impedance of the material to be processed, a larger current begins to flow through the pulsing circuit, which is measured by the current probe inserted in the circuit. This information allows one to control the pulsing process on each individual segment, for example, to set the pulsing end time. The applicator represents an important changeable part that can be modified under the natural product that will be electrically processed.

Figure 2. View of the practical PEF cooking device

The left side of picture shows the changeable applicator, while the basic electronic part can be seen on the right. The applicator, in this case, is represented by a pair of contacting planes, each of which is formed by nine individual metallic segments (3 × 3 cm) gradually coming into active contact over time

RESULTS AND DISCUSSION

Applicator. The above-mentioned aim is achieved by providing a PEF device comprised of an AC voltage source (in the basic electronic part) and two contact electrodes in the changeable applicator. Each contact electrode is divided into nine segments (Figure 2). The whole food preparation process is controlled by a control unit controlling the AC modified square wave voltage source and the switching of the individual electrode segments.

The most important technical feature of this device is the division of each contact electrode into several segments. This allows one to distribute the required power input more evenly over time and to automatically control the efficiency of the pulsation process on the smaller volumes of material to be processed. Thanks to the segmentation of the electrodes, the food to be treated can be gradually subjected to a pulsed electric field, thus sufficient food processing can be achieved with a substantially lower magnitude of the electric current.

Due to the better contact with the processed food and the effort to achieve the largest possible contact area for a successful pulsation, the segments of the common electrical electrodes are flexibly placed. The electrode containing the flexible segments adapts to the inserted material (food), and thus the contact surface is increased.

Basic electronic part. An important technical feature of the device is the AC power source. Previously proposed devices for the treatment of foods by pulsed electric field use direct current sources (Blahovec et al. 2017; Vorobiev and Lebovka 2020). The use of alternating current reduces the effect

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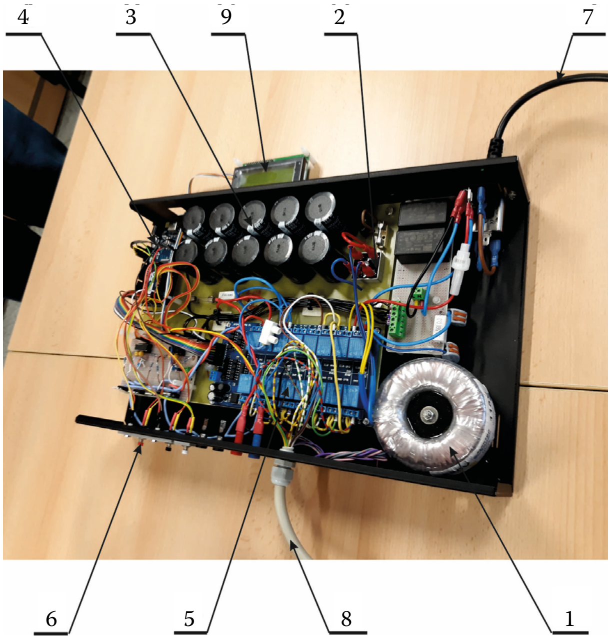

Figure 3. Basic electronic part of the functional device for food electroporation

1 – toroidal isolating transformer; 2 – rectifier module; 3 – capacitor bank; 4 – control unit (Arduino microcontroller); 5 – relay field; 6 – switch control button; 7 – mains 230 V supply cable; 8 – cable to applicator; 9 – information display

of the electrochemical processes on the electrode surface, and, thus, leads to the lower contamination of the electrodes, when compared to the use of direct current (Tatum 2021). As was described in the Material and Methods section, the device further is comprised of a current probe which allows the control unit to automatically regulate the pulsation efficiency (to disrupt the cell membranes) and to terminate the pulsation when a predetermined current flow rate limit is exceeded (indicating the complete or desired disruption of the cell membranes in the food) or when the current flow rate does not increase any more (indicating the maximal cell membrane disruption). Based on the knowledge of the behaviour of a particular food during the PEF treatment, it is possible to simplify the device. For example, during the preparation of carrots, it turned out that five pulses are enough to completely disintegrate the carrot tissue. It is, therefore, sufficient to set a fixed number of pulse repetitions.

The device is supplied from the mains by an isolating transformer, which reduces the supply voltage. In the rectifier module, the supply voltage is then rectified to charge the capacitor bank. The capacitor bank consists of ten capacitors connected in parallel. The voltage on the capacitors is 163 V. This represents a final electric field strength of more than 500 V·cm^{-1} at a sample thickness of approx. 3 mm to be processed between the electrodes. Discharging the capacitor is the oldest concept of electroporation pulse generation (Reberšek and Miklavčič 2011). The AC voltage generator uses an H-bridge, which switches the plus and minus with a frequency of 18 kHz. The H-bridge is fully controlled by the control unit.

The control unit uses a programmable Arduino microcontroller (Arduino 2018). The Arduino microcontroller controls the AC voltage generator. Furthermore, the control unit controls the electrode segment switching. For this purpose, the device is comprised of a relay field in which the control unit switches the relays and, thus, determines the segment of the contact electrode to which the pulse is sent. The control unit was also configured to automatically control the end of the pulsation in the individual segments. It receives an analogue signal from the current probe. Before the first pulse in each of the segments, the value of the initial impedance can be measured using an auxiliary source of low no electroporating AC voltage and the current value reading. Then this impedance can be recorded in the memory of the control unit. In the following pulses, the increase in the value of the impedance can be monitored. When the impedance value falls under a pre-defined limit in one of the segments, the pulsation in that segment is terminated because the cell membranes in the food processed in that segment are already disrupted to a pre-defined extent. The pulsation is also terminated when the impedance of the segment no longer decreases for a pre-defined time period. However, it is also possible to fix the number of pulsing cycles, e.g. based on previous experiments. This setting was used for particular case described in this article. The described device is the subject of Czech national patent No. 308 548 and has currently been submitted for a European patent (Blahovec et al. 2020). The practical design of the basic electronic part is evident from Figure 3.

Based on our experience with this device, it can be stated that the pulse processing of nine carrot pieces took up to 30 seconds. After this time, the device turned itself off and announced the end of the electroporation. The mechanical part of the device was then opened. Only a negligible temperature

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Figure 4. View of the surface of one of the segments after removing the pulsed carrot sample

The stainless steel is dirty. A drop of carrot juice can be seen in the lower right-hand corner of the image

increase was detected in the tested carrot samples (up to 2 °C) after the PEF application. Traces of loose carrot juice were visible on the individual segments of the device. All the carrot pieces were demonstrably processed by the PEF technology.

Shortcomings and further development. However, in terms of practical use in the kitchen, the function of the PEF cooking device is still limited. Problems with the resilient mounting of the individual segments were noted during the practical testing. The surface of the individual stainless-steel segments gradually became dirty (Figure 4) during use. It is also necessary to better seal the individual segments against the juice being released from the processed food. All of these issues need to be considered in the further development with respect to different processing products also.

CONCLUSION

A functional sample of kitchen equipment for PEF vegetable treatment was developed and manufactured. The division of the electrodes into nine self-operating segments enabled the preparation of a large amount of food at once without the need for extreme instantaneous power. The entire electroporation process can be automatically controlled based on the data from the current probe, which can ensure the perfect electroporation of all processed food.

REFERENCES

Arduino. (2018): What is Arduino? Available at https://www.arduino.cc/en/Guide/Introduction (accessed Dec 9, 2021).

Blahovec J., Kouřím P., Kindl M. (2015): Low-temperature carrot cooking supported by pulsed electric field – DMA and DETA thermal analysis. Food and Bioprocess Technology, 8: 2027–2035.

Blahovec J., Vorobiev E., Lebovka N. (2017): Pulsed electric fields pretreatments for the cooking of foods. Food Engineering Reviews, 9: 226–236.

Blahovec J., Kumhála F., Lev J., Kouřím P., Jošt B. (2020): Device and method for preparing food by pulsed electric field. Czech national patent No. 308 548. Oct 7, 2020.

Cortese P., Dellacasa G., Gemme R., Bonetta S., Bonetta S., Carraro E., Motta F., Paganoni M., Pizzichemi M. (2011): A pulsed electric field (PEF) bench static system to study bacteria inactivation. Nuclear Physics B–Proceedings Supplements, 215: 162–164.

Dunn J. (1996): Pulsed light and pulsed electric field for foods and eggs. Poultry Science, 75: 1133–1136.

Elea. (2021): Elea Pulsed Electric Field Solutions. Available at https://elea-technology.com/ (accessed Dec 8, 2021).

Energy Pulse Systems. (2021): Designing Energy That Works With You. Available at http://energypulsesystems.pt/eps/solutions/ (accessed Dec 8, 2021).

Goettsch C., Roelofs H. (2014): Stew cooked in minutes. The sustainable breakthrough in food preparation. Voedingsindustrie, 2: 8–9.

Liegey P. (2002): Hedonic quality adjustments in the U.S. CPI: A statistical agency perspective. Mannheim, US Bureau of Labor Statistics.

OptiCept. (2021): More Olive Oil at Better Quality. Available at https://www.opticept.se/olivecept/ (accessed Oct 8, 2021).

Pulsemaster. (2021): Pulsed Electric Field Processing for the Food Industry. Available at https://www.pulsemaster.us/ (accessed Dec 8, 2021).

Reberšek M., Miklavčič D. (2011): Advantages and disadvantages of different concepts of electroporation pulse generation. Automatika, 52: 12–19.

Tatum J. (2021): Electricity and Magnetism. Available at https://phys.libretexts.org/Bookshelves/Electricity_and_Magnetism/Book%3A_Electricity_and_Magnetism_(Tatum) (accessed Dec 9, 2021).

Toepfl S., Siemer C., Saldaña-Navarro G., Heinz V. (2014): Chapter 6 – Overview of pulsed electric fields processing for food. In: Sun D.-W. (ed): Emerging Technologies for Food Processing. 2nd Ed. San Diego, Academic Press: 93–114.

https://doi.org/10.17221/96/2021-RAE

Universal Appliance and Kitchen Center. (2018): The History of the Oven. Available at https://www.uakc.com/blog/the-history-of-the-oven/ (accessed Dec 8, 2021).

Van Oord G., Roelofs J.T.M. (2016): Low field strength PEF cooking. Patent EU WO 2016008868 A1. Jan 21, 2016.

Vitave GmbH. (2021): Pulsed Electric Field Systems. Available at https://www.vitave.com/products/pef-systems (accessed Dec 3, 2021).

Vorobiev E., Lebovka N. (2020): Processing of Foods and Biomass Feedstocks by Pulsed Electric Energy. Cham, Springer International Publishing.

Wek-Tec. (2021): Advanced Custom Pulsed Power UV to IR and EMF R&D and Pilot Systems from Germany. Available at http://www.wek-tec.de/wt-systems.htm (accessed Dec 8, 2021).

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