ETHIOPIAN INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH

eISSN: 2349-5715 pISSN: 2349-5707

Volume: 10, Issue 12, Dec-2023 SJIF 2019: 4.702 2020: 4.737 2021: 5.071 2022: 4.919 2023: 6.980

RESEARCHING ON THE PROCESS OF CONVECTIVE DRYING OF JERUSALEM ARTICHOKE TUBERS UNDER THE INFLUENCE OF PULSED ELECTRIC FIELD

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Abstract: Commercially Jerusalem artichoke tubers are valuable raw material to produce insulin, fructose, treacle and alcohol. Fast decreasing of quality at traditional storage as a tuber raw material makes difficult to apply it during a year. For that matter, drying is offered as the most suitable preservation method of Jerusalem artichoke tubers. The purpose of work is determine the influence of a pulsed electric field (PEF) treatment, enhancement of efficiency and lowering energy consumption in a process of drying of crushed Jerusalem artichoke tubers.

Keywords: Jerusalem artichoke, PEF, convective drying, processing, quality of product.

Introduction. The perennial jerusalem artichoke plant has healing qualities. Tubers contain nitrogen compounds, organic and fatty acids, vitamin C and vitamin B complex, and the soluble polysaccharide inulin. The minerals found in Jerusalem artichokes include copper, magnesium, silica, zinc, phosphorus, iron, and potassium. Numerous studies support the usefulness of using jerusalem artichokes as a functional food. Jerusalem artichoke tubers can be added to food as a dietary supplement, especially for diabetics undergoing extensive therapy, to help regulate metabolism. The polysaccharide inulin, which is a representation of the carbohydrates found in tubers, provides an explanation for this. Inulin is broken down into fructose during digestion. Fructose, on the other hand, is swiftly converted into glycogen, does not raise blood sugar levels, and is readily absorbed by humans. Jerusalem artichokes have the ability to eliminate radioactive materials, salts, and heavy metals.

Various treatments before the drying process are applied more and more often. By modifying the properties of a particular tissue, they increase the drying rate and improve the quality of the material. Recently, the application of a pulsed electric field (PEF) has been used more frequently as a pre-treatment method before drying. It is one of the most promising nonthermal treatments before drying. The main mechanism of PEF is based on the gentle opening of the cell membrane as a result of electroporation, i.e. forming irreversible or reversible pores in the cell membrane. Therefore, the pulsed electric field induces an increase in the permeability of the cell membrane. Pulsed electric fields can induce physical modifications in the treated tissue. Electric pulses of appropriate intensity damage the cell membrane of the material, which enhances the diffusion of water. This accelerates the drying process and, thus, reduces the degradation of important bioactive compounds, e.g. flavonoids in mangoes. The application of a pulsed electric field before vacuum drying also allowed the authors to increase the retention of β-carotene in the obtained dried carrot. Research carried out on the blueberry shows the possibility of improving vacuum drying by using electric pulses as a pre-treatment, without adversely affecting the quality of the obtained dried material (the contents of anthocyanin and vitamin C). However, the amount of energy supplied by the PEF should be carefully dosed, because of the "overtreatment" phenomenon of the material that may lead to the destruction of important food ingredients. So far, the impact of the pulsed electric fields on the course of freeze-drying apples have been studied as well as on convective drying of that fruit. However, there are no reports on the possibility of applying this nonthermal pre-treatment to improve the vacuum drying of apples. Therefore, this research aimed to determine the effect of a pulsed electric field pre-treatment

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on the convective drying of Jerusalem artichoke tubers and the selected properties of the obtained dried material (total phenolic content – TPC, antioxidant activity, microstructure).

Material and methods. Material. The research was performed on the Jerusalem artichoke tubers variety "Fayz baraka". Freshly plucked Jerusalem artichoke tubers is cleaned. The most standard jerusalem artichoke tubers in terms of shape, colour, and maturity were selected for the tests. Before starting the technological operations, the initial dry matter content of the fresh jerusalem artichoke tubers was 80 ± 3%.

Pulsed electric field pre-treatment. The pulsed electric field pre-treatment of jerusalem artichoke tubers was carried out in a batch system. To achieve this, one jerusalem artichoke was placed inside a chamber with 2 L capacity, which was equipped with two parallel stainless-steel electrodes (with a distance between the electrodes of 24 cm). The pulsed electric field parameters were: an electrode voltage of 6,7,8 kV an electric field strength of 1 kV·cm^{-1} – which corresponds with the mean electric field strength inside the chamber (Grimi et al. 2010), a pulse frequency of 50 Hz, and a pulse width of 7 microseconds. The number of rectangularpulses depended on the amount of supplied energy. The specific energy intake W_{spec} (kJ·kg^{-1}) and electric field strength E (kV·cm^{-1}) were calculated according to the following Equations (1–2):

$$W_{spec} = \frac{IUtn}{m} \qquad (1)$$

$$E = \frac{U}{d} \qquad (2)$$

where: n – the number of pulses; m – the mass of the treated samples (kg); U – the voltage (kV); I – the current (A); t – a pulse duration (s); d – the distance between the electrodes (cm).

The conductivity of the untreated and PEF-treated whole jerusalem artichoke tubers was measured using the dual needle platinum electrodes method at a frequency of 50 Hz (pH/conductivity meter CPC-401, Elmetron, Zabrze, Poland). Based on the obtained results, the CDI (cell disintegration index) was calculated according to Equation (3)

$$CDI = \frac{\sigma - \sigma_i}{\sigma_d - \sigma_i} \qquad (3)$$

where: σ – the conductivity of the tissue after applying the pulsed electric field (µS); σ_i – the conductivity of the intact tissue (µS); o_d – the conductivity of the maximally ruptured tissue (sample treated with an energy input of 50 kJ·kg^{-1}) (µS).

The drying was performed under pressure set at 4 kPa in all the variants, but the temperature was varied (40 °C, 55 °C, and 70 °C). This level of pressure should provide a relatively low boiling temperature of water (T_b ≈30 °C) (Agrawal and Menon 1992), and significant cooling of the material during the water evaporation may also occur (Liu et al. 2018). The sliced apples were placed in a single layer on a perforated tray and the sieve load was 2.1 kg per square meter. During the drying, the weight of the apples was continuously (without any interruption in the drying process, using the same sample throughout the entire process) recorded every 10 min, which served to determine the drying time (time to achieve MR = 0.02 by dried apples) (Sacilik and Elicin 2006; Piotrowski et al. 2007; Schultz et al. 2007; Beigi 2016). The MR (moisture ratio) was calculated according to Equation (4) (Matys et al. 2021):

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$$MR = \frac{M_\tau}{M_o} \quad (4)$$

where: M_τ – the water content in samples during the drying (kg H_2O per kg of dry matter); M_0 – the initial water content in the samples (5.9 kg H_2O per kg of d.m.).

RESULTS AND DISCUSSION: Cell disintegration index. The cell disintegration index indicates the cell damage and ranges from zero to one. Zero stands for the intact tissue and one stands for the maximally ruptured material (Lebovka et al. 2007). As can be seen from Table 1, the degree of damage to the apple tissue through the application of electric pulses during the pre-treatment increased along with the increase in the amount of supplied energy (CDI ranged between 0.29–0.55). The obtained results correlate with previous published studies (Lammerskitten et al. 2020; Shorstkii et al. 2022).

Both the amount of specific energy during PEF pretreatment and the drying temperature significantly influenced the time of the vacuum drying of the apples ($P < 0.05$). Increasing the drying temperature and, thus, intensifying the convective heat transfer (Lebovka et al. 2007; Liu et al. 2020a), shortened the drying time. For example, vacuum drying the untreated samples at 40 °C, 55 °C, and 70 °C lasted 710, 460, and 320 min, respectively. Moreover, the use of a PEF as the pre-treatment considerably reduced the drying time in each analysed variant. For instance, the drying time of the 40 °C 6 kJ·kg–1 sample was shorter by 22% than that of 40 °C 0 kJ·kg–1 sample. The PEF technology applied before vacuum drying allowed one to decrease the drying time of various materials, such as in potatoes (Liu et al. 2018), carrots (Liu et al. 2020b), blueberries (Yu et al. 2017), and basil leaves (Telfser and Galindo 2019). The increased permeability of the cell membrane and the damaged structure of the material caused by PEFs (more specifically by electroporation) affected the transfer of mass and heat and, thus, led to an improvement in the drying rate (Lammerskitten et al. 2020; Liu et al. 2020a). Nevertheless, in some cases, the application of a higher energy input did not reduce the drying time any further. For example, the drying time of the 40 °C 3.5 kJ·kg–1 sample was longer by 20 min than that of 40 °C 1 kJ·kg–1 sample. Such a situation may be associated with the saturation of electroporation (Lebovka et al. 2004a; Beitel- White et al. 2021) and may indicate that a treatment with an energy input higher than 1 kJ·kg–1 does not bring any further effect. However, it should also be considered that the delivery of high energy during the treatment may result in the overtreatment of the tissue, its collapse, and cause a loss of turgor (Lebov-ka et al. 2004b), which will hinder the water evaporation. Therefore, it is very important to properly select the process parameters.

All discs of one series of experiment were mixed and spread to drying containers (4 PEF; 4 untreated), the structure of which ensured a uniform drying and weighing of the samples. The drying containers consisted of a frame covered with a thin plastic net and a mesh size of 3 mm allowing air to flow through it. The drying of the untreated and PEF-treated samples on top of the containers was done simultaneously and repeated three times. The total mass load per drying cycle was approximately 70 g. Each slice had an initial mass of 0.9 0.3 g. The clearance between the slices varied from 3 to 5 mm. No slices lay on top of each other. As the drying industry uses deferent drying zones with various temperatures and residence times to keep the drying time short but product quality high, the first task of the study was to investigate the drying kinetics of the onions [10]. As PEF pre-treatment alters the product characteristic and drying behavior in terms of an increase in cell disintegration as well as a facilitated moisture release and di

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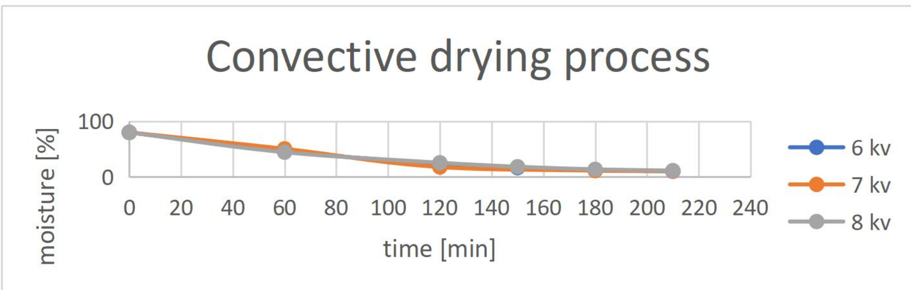
usion, it is important to adapt the drying profile to achieve all the process and quality benefits [17]. Initially, the first and second drying phase were determined by defining the breakpoint (BP) after which the product temperature starts to increase. Therefore, the drying containers and samples were weighed with the precision scale (Kern 440-49A, Kern & Sohn GmbH, Germany, accuracy 0.1 g). Then, all samples were dried in a preheated drying oven (FP 240, Binder GmbH, Germany). The residual moisture Mr of the sample was calculated according to industrial requirements of a certain maximum level of residual moisture left in dried goods. The target moisture of all samples was set to 7%, as this moisture level is common in the onion industry. The values of Mr vary between 100% and 0%, where 100% would be a sample, which consists completely out of moisture and 0% would be a total dry product. The moisture ratio (MR) was calculated for these experiments as well. It is known as the standard method to describe drying kinetics. However, in this particular case, only the values are shown in this study as it is the standard unit used in the industry and it allows a second method to detect the different drying stages. This method to determine the BP includes the calculation of the slope of the residual moisture [10]. The slope represents the percentage drop of Mr in minutes between one measuring point followed by the next measurement point. If the slope reaches the highest intensity, the BP is reached. For the BP determination, the drying process was performed at an air velocity of 0.2 m/s and constant temperatures of 85, 75, and 65 °C. Those slightly higher temperatures in comparison to the first paper (45, 60, 75 The delay point (DP), caused by a reduction in the drying temperature at the BP was evaluated as well.

As the industry reduces the temperature till the end of the drying process to avoid quality losses, the samples were dried at 85 C for the first drying phase and at the BP the drying temperature was reduced to 75, 65, or 55 °C. The drying process, analysis, and calculation were the same as one for determining the BP. were chosen as it turned out that the industry is especially interested in short drying times achieved by high temperatures. Hence, this study also investigated if higher temperatures in combination with a PEF treatment allow for time reduction without quality losses. The surface temperature of the investigated onion discs was measured by means of an infrared thermometer (IR 100, PCE Holding GmbH) each 10 min. Additionally, to obtain the drying curve, all containers were weighed in uniform intervals of 10 min. The drying procedure was performed on jerusalem artichoke tubers, prepared by cutting the fruits into 5 mm thick slices. The convective drying of the untreated and PEF treated jerusalem artichoke tubers was carried out in a laboratory convective dryer. Jerusalem artichoke tubers tubers are fed with 10, 20, 30 pulses under the influence of an electric pulse field. The marked temperature was set at the same 60^0 C for all processes.

Drying time. Figure 1 shows the drying process of the untreated and PEF-treated apples in a curve diagram, while drying time is presented in Table 1.



This table shows how jerusalem artichoke tubers dries to different moisture content during the same time when 10 pulses of 6 7 8 kV are applied.

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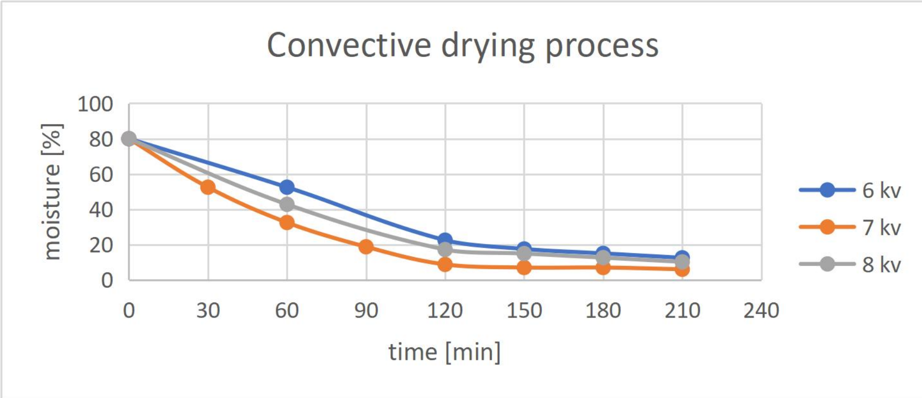

This table shows how jerusalem artichoke tubers dries to different moisture content during the same time when 20 pulses of 6 7 8 kV are applied.

As the drying industry uses different drying zones with low temperatures and residence times to keep the drying time short but product quality high, the first task of the study was to investigate the drying kinetics of the jerusalem artichoke tubers. As PEF pre-treatment alters the product characteristic and drying behavior in terms of an increase in cell disintegration as well as a facilitated moisture release and diffusion, it is important to adapt the drying profile to achieve all the process and quality benefits.

Conclusions: The impact of a PEF pre-treatment on the convective drying and quality of jerusalem artichoke tubers has been investigated. It was shown that applying a PEF pre-treatment of 6,7,8 kv to whole jerusalem artichoke tubers prior to drying resulted in a positive change in the drying kinetics. For drying at a constant temperature of 60 °C, the was achieved 60 min faster. Moreover, PEF treatment resulted in a 25% faster drying process. This allowed us to reduce the drying temperature for the second drying stage earlier, still resulting in an efficient, drying process.

The present research shows that it is possible to optimize the convective drying of jerusalem artichoke tubers with pulsed electric field pretreatment. PEF, by increasing the permeability of the cell membrane, led to a significant reduction in drying time (8–28%). Relationship was found between the amount of energy supplied during PEF pretreatment and the reduction of drying time; therefore, it is worth considering gentler conditions of treatment with an electric field to avoid overtreatment of the material.

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eISSN: 2349-5715 pISSN: 2349-5707

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eISSN: 2349-5715 pISSN: 2349-5707

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