Substantiation of criteria and methods for estimating efficiency of the electric impulse process of plant material

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Abstract. One of the most effective ways to prepare for extracting or removing intracellular fluid from plant material is its electric impulse treatment at initial processing stage before squeezing juice, dehydrating raw materials, drying materials, etc. As the parameters and modes that determine this process can be identified only experimentally, a device including a high-voltage impulse generator was designed. Plant tissue damage degree was assessed by changing resistance and phase shift. Intensive juice extraction was observed when high-voltage impulses in the amount of up to 100 units were supplied to plant material. With continued processing and increase in the number of impact impulses, the intensity of juice yield decreased, and the expended energy was spent on heating the plant material. The evaluation method based on quantitative analysis of pulse shape of flowing measuring current is proposed. The designed digital control device allows confirming the dependence of measured electrophysical parameters on changes occurring in plant material caused by electric impulse processing. The designed algorithm can be used as the basis of automatic control system operation for electroimpulse processing of plant materials before pressing.

1. Introduction
Extraction of juice and removal of excess liquid from plant materials (fruits, vegetables, berries, melons, fodder herbs, etc.) is one of the main technological operations during plant processing. The effectiveness of the implementation of this operation affects the quality and quantity of the finished product, for example, in the drying process, and determines the cost of its production. Therefore, technologies that can solve this problem in the most efficient way in automatic mode are relevant and require close attention not only at processing enterprises of various forms of ownership, but also among research scientists. The electrical energy supply in the form of high voltage impulses to processing facilities is considered to be not only a safe from the point of view of food and environmental aspects, but also energy and resource-saving method of electrophysical effect on raw materials, semi-finished products and materials [1–4]. One of such electrotechnologies, which makes it possible to maximize the resources hidden in plant raw materials, includes preliminary electroimpulse treatment or electroimpulse plasmolysis, which is used in the preparation of fruits and vegetables before squeezing juice of them, drying and other similar operations [5–7]. The technological efficiency of this electric processing is determined by such indicators as the rate of electric energy input into the processed plant material, the amount of absorbed energy, the accompanying temperature conditions, the minimum energy consumption for the process, etc. In this regard, the issue is to identify criterion for assessing the damage degree and to determine its ultimate
value, to propose a method of assessment and an algorithm for its implementation on the basis of nature analysis of energy absorption by plant raw materials.

The purpose of the work is to substantiate the effective criterion for assessing the damage degree to plant tissues during electroimpulse processing of raw materials before pressing and the method for its technical implementation.

2. The methodology of experimental research
To research the process of electric impulse processing of plant raw materials, a high-voltage impulse generator, consisting of a control and a switching units, was designed and manufactured. The main key elements of the switching unit are the high-voltage thyratron and the electrical components. The control unit sets the impulses repetition rate, their number and indicates the state of operation and readiness of the thyratron, on which the switching unit operates. The designed generator is part of an experimental laboratory electrotechnological device (figure 1), consisting of a high voltage generator, a high voltage capacitor, a cell for electropulse processing of plant materials, a high voltage impulse generator, a control and measuring complex, containing a digital oscilloscope, an LCR meter, digital scales, a generator of rectangular measuring impulses, a microscope and a press.

Figure 1. Experimental laboratory electrotechnological device for studying the process of electroimpulse processing of plant materials: 1 – control unit for the generator of high voltage impulses; 2 – switching unit of the generator of high voltage impulses; 3 – cell for electropulse processing of plant materials; 4 – vegetable raw materials; 5 – high-voltage capacitor in the housing and with the anti-corona screen; 6 – high voltage resistor; 7 – high voltage source.

The experimental device makes it possible to study quite fully and comprehensively the process of electric impulse treatment of plant materials before pressing. The high-voltage impulse generator is capable of generating impulses with the frequency in the range from 1 to 400 Hz and can bring a predetermined number of impulses to the processing object. Impulse duration is regulated by the capacitance of the storage capacitor. The adjustable generator body allows changing the amplitude of the impulses supplied to the processing object from 0.5 to 16 kV. Due to the exploitation features of the thyratron, high-voltage impulses can be obtained with a sharp front, which allows the process of rapid energy input to plant tissue, and with an exponential cut. These impulse shapes are technologically effective for implementing research according to the issues that have been already solved to study and compare the effectiveness of various impulse shapes for microorganisms’
inactivation [8, 9]. But, at the same time, impulses that are close to a rectangular shape will also provide technological efficiency with better energy performance with less heat generation at the processing object and high energy absorption rate by plant tissue.

3. Results and discussion
To study juice yield dependence on the electrical impulse energy absorption by the plant tissue, pre-prepared samples of plant material were selected. Apple disks of 30 mm in diameter and 5 mm high are placed at one time in the processing cell that is included in the discharge cell of the high-voltage impulse generator circuit. After electric impulse treatment, the plant material is transferred to the press with fixed pressure of 218.62 kPa, where juice is extracted from apple raw materials. Then the obtained material from the press was weighed on digital scales. The results of experimental studies on the juice yield from processed raw materials are presented in figure 2.

![Figure 2](image)

**Figure 2.** Dependences of juice yield on the number of impact impulses and processing voltage at apple raw materials.

The analysis of the obtained data allows revealing the achieved effect of electric impulse processing of plant materials before the subsequent juice pressing by the pressing method. The dependences presented in Figure 2 indicate that the electrical energy absorption by the plant tissue of the processed raw materials at the initial stage is more intense than during subsequent exposures to high-voltage impulses of 100 units or more. This is caused by more serious and large-scale violation of the integrity of the plant cells' membranes that results in more freely extraction of the intracellular fluid from the processed raw materials during the initial time interval.

Plant samples of the same geometric dimensions and parameters as in the previous study were used to study the changes in the electrophysical properties of plant tissue from absorbed electrical energy. Plant samples were placed in the cell to which the RLC-meter was connected. Phase shift and impedance of the loaded material were recorded. At the end of the measurements, the RLC-meter was turned off and the rectangular measuring impulse generator, shunt and digital oscilloscope were connected to the cell to take the oscillogram of the current impulses flowing through the plant object. Then, according to the research tasks, the number of high-voltage impulses was supplied to the cell, and upon completion of processing, the measuring equipment was again connected to the object to record the changed parameters of the plant tissue of the raw material and to take the oscillogram of the measuring current. The damage degree to the plant tissue, estimated by the initial and changed resistance of the plant tissue during processing was defined as the main characteristic, with which it was decided to compare alternative methods for assessing the degree of damage [1].

The results of experimental research on the dependence of electrical properties of the plant tissue of apple raw materials on the absorbed energy during electric impulse processing are presented in figure 3.
The analysis of the obtained experimental data reveals that there is direct dependence of the change in the impedance and the phase shift during the electric impulse processing on the amount of absorbed energy (the number of acting impulses), which can serve as an estimate characteristic of the final product yield (juice). At the graphs (Figures 2 and 3), the same character of the curves is clearly observed: the initial sharp increase in the juice yield, decrease in the impedance and decrease in the phase shift up to the impact of 100 impulses on the plant tissue and the subsequent slow monotonous change in the listed characteristics when processing is continued.

Thus, the changes in the phase shift and impedance qualitatively reflect decrease in the capacitive component due to the released intracellular fluid, which affects the decrease in the capacity of "natural capacitors" (violation of the semipermeable properties of the membranes of cell structures) and, as a consequence, change in the angle of phase shift [10]. The obtained oscillograms of the current impulses, flowing through the plant material before and after processing, present decrease in the capacitive component by changing the current impulse shape. This method can be an alternative, fast and accurate way to assess the depth of damage to plant materials, not only under laboratory conditions, but also in line production due to the high speed of measurements.

In [10], a method is proposed for assessing the damage degree to plant materials on the basis of the analysis of changes in the capacitive component of the electric substitution model of plant material during electric impulse processing. The functional diagram of the device for assessing the damage degree to plant tissues of processed raw materials is presented in figure 4.

Figure 3. Dependences of the phase shift and the impedance of the plant tissue of the processed raw materials on the absorbed energy.

Figure 4. Functional diagram of the device for assessing the damage degree to plant materials. 1 – generator of rectangular measuring impulses, 2 – measurement chamber, 3 – current-voltage converter, 4 – rectifier, 5 – amplitude meter, 6 – comparing element, 7 – filter, 8 – repeater, 9 – measuring device.
The device manual: the voltage from the generator of rectangular measuring impulses is supplied to the measuring chamber, in which the object of assessment is located; the measuring current impulses flowing through the circuit pass through the current-voltage converter and are converted into a measuring signal supplied to the rectifier from the output whose formed voltage is supplied to the amplitude meter and comparison element.

Then the amplitude meter generates constant voltage numerically equal to the amplitude and transfers it to one of the inputs of the comparison element, where the voltage received from the output of the rectifier is "subtracted" from the voltage amplitude.

The resulting voltage is applied to the filter, repeater and measuring device, the readings of which reflect the damage degree to the plant raw materials in voltage units. The maximum voltage on the measuring device corresponds to the undamaged plant tissue of the processed raw materials, and the minimum voltage corresponds to the maximum damaged plant tissue. This is caused by the measuring current passing through the damaged plant tissue and repetition of the impulses of the applied voltage due to the lack of the capacitive component.

The impulses of the measuring current passing through the intact plant tissue will have exponential decline, which decreases as the plant tissue is damaged, and which, after subtracting of voltage equal by amplitude, will be filtered and output to the measuring device.

The results of comparing measurements of the damage degree by the designed device, as well as the nature of the change in impedance and phase shift measured by the RLC-meter, are presented in figure 5 in relative units.

![Graph](image_url)

**Figure 5.** The change in impedance and phase shift measured by the RLC-meter and the damage degree measured by the designed device.

The obtained experimental results allow us to state that the method described above and the designed device are suitable for assessing the degree of damage to plant materials and, as a result, for using it at automatic production line of preliminary electric-impulse processing of plant materials before extraction, to assess the efficiency of the processing process.

### 4. Conclusion
The largest amount of juice is released at the initial processing period when exposure to high-voltage impulses leads to a sharp and intense change in the electrical parameters of plant materials (impedance and phase shift).

It is possible to control the process of electric impulse processing and the energy supply using the method for assessing the damage degree to plant tissue based on the analysis of measuring current impulses flowing through the processed raw materials and characterized by the change in the phase shift.
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