ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Plant Tissue Sensitivity To Electrical Impulse.

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ABSTRACT

At present, innovative technologies of agriculture and processing of plant raw materials and material very often use electric impulses for the non-thermal destruction of the structure of plant tissues. One of the factors determining the depth and extent of such an impact is the sensitivity of the treated tissues to them. The reaction of plant tissue to electro-impulse effects can be fixed by the degree of its damage, depending, for example, on the strength of the electric field. Studies have shown that the creation of tension in plant tissue, in which the degree of damage reaches the maximum value, leads to irreversible tissue damage, which was acted upon by high-voltage pulses, thus achieving the planned technological effect - a violation of the integrity of the tissue cell membranes. The degree of damage to plant tissue of various plant objects increases with the increase of the electric field in the tissue, reaching its limiting value. Quantitatively determines the sensitivity of plant tissue to damage the exponent n, by the value of which it is possible to conclude: what tissues, and which plant objects are more sensitive to electropulse damage, and which are less sensitive.
Keywords: plant tissue, electrical impulses of high voltage, degree of damage, electric field strength.

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ISSN: 0975-8585

INTRODUCTION

At present, the methods of processing plant objects, characterized by a non-thermal method of destruction (disruption of normal vital activity) of plant tissues, are becoming increasingly important. To these methods, first of all, electropulse high-voltage actions are applied, which are used for processing plant raw materials and materials in the processing and food industries, as well as processing of cultural and weed plants, hay grasses, etc. in the crop sector of agriculture. Electropulse technologies are characterized by minimal energy and processing time, high technological efficiency, environmental and food safety.

In plant growing, high-voltage electric impulses are used in the destruction of weeds and unwanted vegetation [5, 11], thinning of crops, [13] pre-harvesting of sunflower and tobacco [3, 5], processing of hay grasses before drying [7], etc.

In the production of food products, electropulse effects are used to inactivate harmful microorganisms and bacteria [12], so in the production of fruit and vegetable juices, effective inactivation of bacteria is observed, accompanied by a slight deterioration in taste of the products obtained, their flavor, color and nutritional value [2]; are used to obtain high-value metabolites in the food industry [8], as well as to increase the yield of fruit and vegetable juices [6, 10]; accelerate mass transfer in the process of drying food products [1], etc.

At the heart of all the above options for the use of high-voltage electropulse actions, the effect of the disruption of the normal functioning of membrane envelopes of cellular structures of plant tissues is achieved, which is achieved due to their irreversible damage.

Therefore, the purpose of the study presented in the article is to elucidate the nature of the sensitivity mechanism of plant tissue of whole plants, plant raw materials and material, the parameters of the electro-impulse effect and, first of all, the electric field strength in the tissue.

MATERIALS AND METHODS

The sensitivity of plant tissue to electrical effects is suggested to be estimated with the help of such a quantitative index as the degree of its damage (S_n), which means a quantity whose numerical value is determined by the ratio of the total resistance of the tissue (or its active component) to electrical treatment to tissue resistance during processing on the fixed frequency of the measuring current is fixed, in our case at the frequency f = 10 kHz [5, 9].

To establish the analytical relationship between the degree of damage to the plant tissue of the processed raw materials or material and the intensity of the electric field (E), as well as the energy of the acting impulses (W), we use expression (6) to connect the depth (degree) of damage with the intensity of the action and the time of action of the damaging factor [3, 4, 14]:

$$S_n = k_s \cdot E^n \cdot t^q, \qquad (1)$$

where $E = U_0 / l_{pt}$ is the average electric field strength in the treated plant tissue, kV / m; t - action time or pulse duration, s; n - a constant that determines the relationship between the change in the intensity of the field in plant tissue and the degree of its damage, can take integral and fractional values; q - the constant, which determines the relationship between the time of exposure to plant tissue and the degree of its damage, can take integral and fractional values; $U_0$is the initial voltage of the discharge circuit applied to the sample of plant tissue of length l_{pt} and the cross-sectional area F_{pt}, kV; k_s is the proportionality coefficient, (cm / kV) n · c^{-1}.

Detailed studies and the study of the effect of electropulse actions were carried out with weeds, sunflower and tobacco plants, and therefore in the proposed analysis the bulk of the material will relate to irreversible damage to the plant tissues of the listed plants, although in experimental studies, vegetable raw materials, fruits, and melons were also studied. The investigated objects are parts and pieces of samples of plant origin of finite length l_{pt} and cross-sectional area F_{pt}. In analytical expression (7), for the convenience of the analysis, the exposure time t is taken in the first degree, which corresponds to the main linear portion of the dependence $S_n = f(E)$. This assumption is possible since the investigated plant tissues were affected by single pulses that had the same duration in each series of experiments:

$$S_n = k_s \cdot E^n \cdot t = k_s \cdot \left(\frac{R_{pt} \cdot i}{l_{pt}}\right)^n \cdot t = k_s \cdot \left(\frac{R_{pt}^{n-1} \cdot i^{n-2}}{l_{pt}^n}\right) \cdot W =$$
$$= k_s \cdot \left(\frac{R_{pt}^{n-1} \cdot i^{n-2}}{l_{pt}^n}\right) \cdot m \cdot W_1 = k_s \cdot \left(\frac{R_{pt}}{l_{pt}^2}\right) \cdot m \cdot W_1 \cdot E^{n-2} = ,\qquad (2)$$
$$= k_s \cdot \left(\frac{\rho_{pt}}{l_{pt} \cdot F_{pt}}\right) \cdot m \cdot W_1 \cdot E^{n-2}$$

where i is the average value of the current flowing through the plant tissue, A; U_0 is the initial voltage of the discharge circuit applied to a sample of plant tissue of length l_{pt}, kV; k_s - coefficient of proportionality, (cm / kV) n · c^{-1}; $P_{pt} = ((p_{pt} \cdot l_{pt}) / F_{pt})$ - resistance of the investigated sample of plant tissue with specific electric resistance ρpt, length lpt and cross-section area F_{pt}, Ohm; $W = W_1 \cdot m$ is the total energy, J; $W_1 = i^2 \cdot R_{pt} \cdot t = 0.5 \cdot C \cdot U_0^2$ is the energy of a single pulse, J; C - storage capacity of the discharge circuit, F; m is the number of acting pulses.

Preliminary analysis of expression (2) shows that the degree of damage to plant tissues S_n depends on the electric field strength in them E, and the character of the dependence is determined by the value of some power exponent n.

RESULTS AND DISCUSSION

Plant tissue of weeds, sunflower and tobacco plants, objects of plant origin has the same structure as an object of electrical impact, and therefore the nature of the dependencies $S_n = f(E)$ will be the same. As a confirmation, consider the behavior of the indicated dependences for sunflower (Figure 1), pumpkin (Figure 2) and some species of weeds (Figure 3).

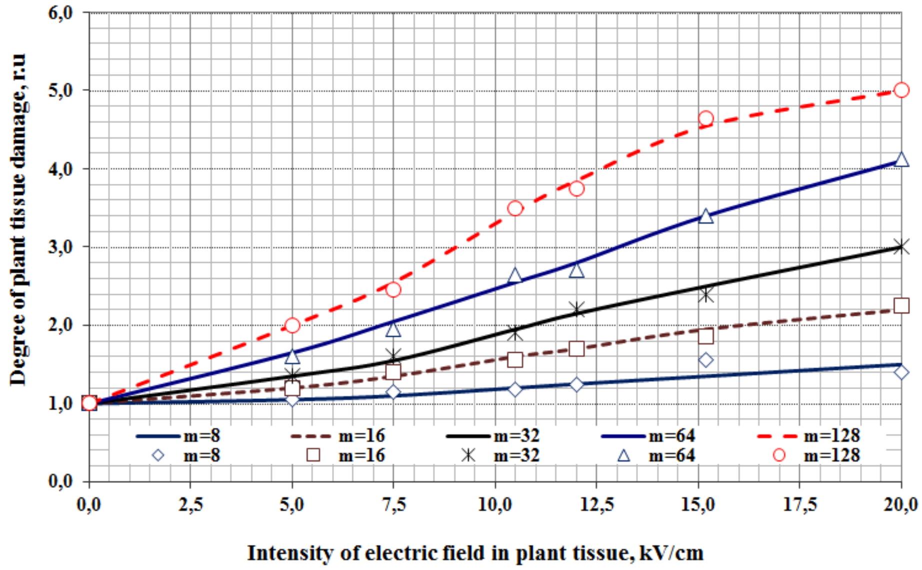


Figure 1: Dependence of the degree of damage (S_n) of plant tissue of the stalk of sunflower plants (the phase of development is "waxy ripeness"), the intensity of the electric field (E) in the tissue with a different number of acting impulses $m = var$ and constant capacitances of the discharge circuit C = 47 pF, and also inductance L = 5 μH

ISSN: 0975-8585

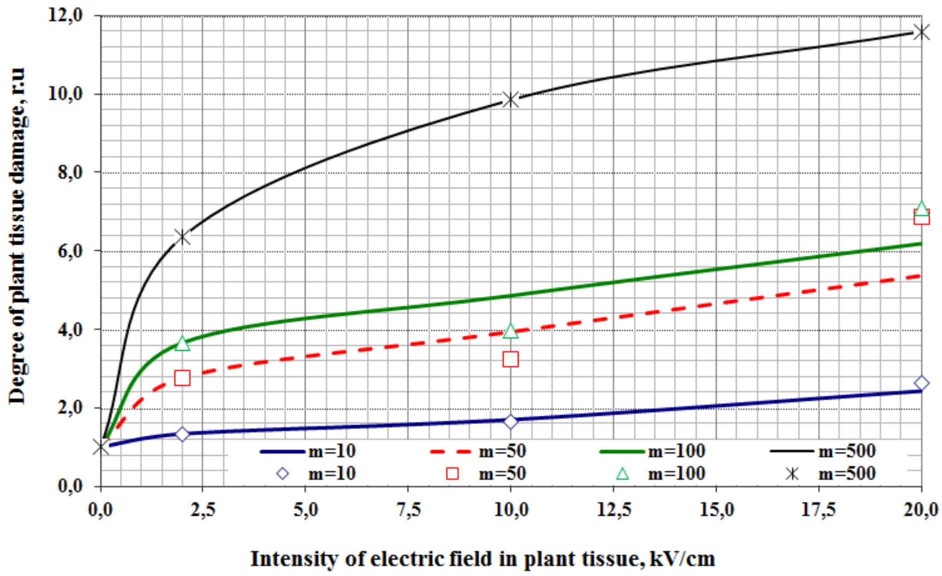
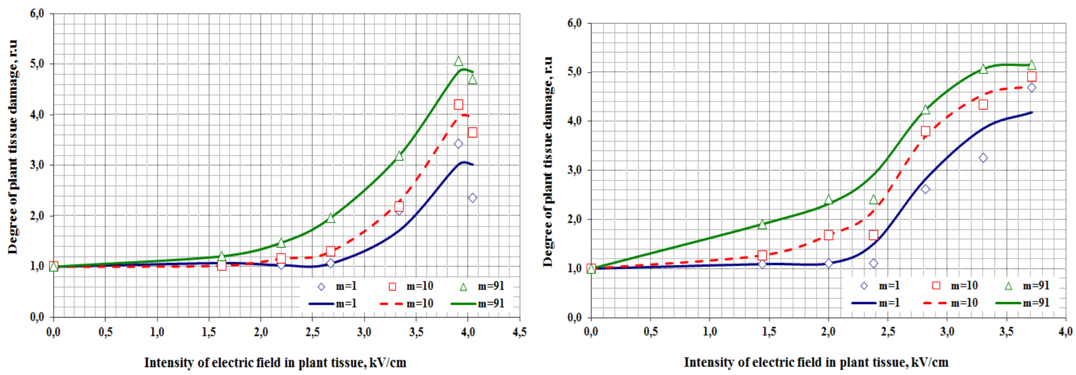


Figure 2: Dependence of the degree of damage (S_n) of the plant tissue of the pumpkin «Gribovskaya Zimnay» from the intensity of the electric field (*E*) in the tissue with a different number of acting pulses *m = var*and constant capacitances of the discharge circuit *C* = 365 pF, as well as inductance *L* = 25 mcH



(a) (b)

Figure 3: Dependence of damage degree (S_n) of plant tissue of the root system of weeds: (a) - *Euphórbiavirgáta L.*; b) - *Cirsiumarvense L.* from the intensity of the electric field (*E*) in plant tissue with a different number of impulses *m = var* and constant values of the capacity of the discharge circuit *C* = 1000 pF, as well as inductance *L* = 110 μH

Quantitatively, the degree of damage, as well as the nature of the dependence $S_n = f(E)$ (Figures 1-3) are determined by the value of the index *n*, which was found for the following plant tissues: for tobacco, *n* = 1.26; for sunflower *n* = 1.5; for the aloe plant *n* = 0.75; for apple pulp *n* = 2.45 [3, 14]. Here it should be noted the obvious fact - considering the electrical processing of various plant objects, you can see that the exponent *n* depends on the number of impulses *m* or the energy input *W* applied to the object. Therefore, the values of *n* given above should be characterized as averaged for the process of electropulse treatment.

Quantitatively, the exponent *n* was on the main linearly increasing portion of the dependence $S_n = k_s \cdot E^n \cdot t$, which was constructed on a logarithmic scale, and the value of *n* was determined as the value of the tangent of the slope of the obtained lines to the abscissa axis. Each dependence is constructed for a specific number of acting pulses with a constant value of the storage capacitance of the capacitor bank of the discharge circuit. The average values of the indicator *n* for some weeds are presented in the table.

ISSN: 0975-8585

Table 1: The average values of the index *n*, which determines the relationship between the change in the intensity into the plant tissue and the degree of damage for various sections of weeds

Weeds	The averaged values of the exponent *n* for different species of weeds and plant tissues of the plots:			
	Stem	Area with the root collar	Root	Average
Cirsiumarvense L.	1,15	1,24	1,22	1,20
Sonchusarvensis L.	1,19	1,23	1,25	1,22
Euphórbiavirgáta L.	1,06	1,21	1,14	1,14
Lactúcatatárica L.	1,17	1,25	1,26	1,23
Amaranthusretroflexus L.	1,22	1,31	1,21	1,25
Average value	1,16	1,25	1,22	1,21

Differences in the numerical values of the index n, most likely, are explained by the different sensitivity of plant tissue of weeds to the impact on it of electrical impulses of high voltage.

It should be noted that there is a direct correlation between the value of the exponent n and the number of impulses m, and, consequently, on the energy absorbed by the plant tissue. The more impact pulses are fed to the plant sample, the higher the value of the index n, for example, for the tissues of the plant *Euphórbiavirgáta L*. at m = 10, the exponent is n = 0.63, and for m = 1000 the index increases to n = 1.796.

To confirm the above assumption about the different sensitivity of the tissue, consider the relationships $S_n = f(E)$ constructed for weeds of different biological groups (Figure 3), which have a pronounced *S*-shaped character, which emphasizes the presence of an initial site with an insignificant increase in the degree of damage with an increase in the value of tissue tension and a site with a very high rate of change in the degree of damage, as well as a site where, as the stress increases, a significant change in the degree of damage is no longer observed that is, the area where the tension reached its limiting value.

The nature of the curves presented in Figure 3 makes it possible to draw the following conclusion: considering the dependence $S_n = f(E)$ on the number of acting pulses equal to unity, it can be noted that the plant tissue of the root system in the plant *Cirsiumarvense L*. reaches a deeper damage than the *Euphórbiavirgáta L*. and *Cirsiumarvense L*. But at the same time, for m = 91, the value of the degree of damage to plant tissue practically becomes the same, and the behavior of the dependencies is very similar to each other.

In electrical processing, the applied initial voltage of the discharge circuit U_0 determines the value of the electric field E in the plant tissue. Of interest is its value, in which the degree of damage to the plant tissue reaches the maximum (maximum) value of $S_n = S_{nmax}$. It is the creation of such tension in plant tissue, or the current density flowing through it, leading to irreversible damage to the tissue, which was acted upon by high-voltage pulses.

CONCLUSION

Analysis of the presented research results allows us to draw the following conclusions:

1) degree of damage to plant tissue of various objects of plant origin increases with increasing intensity of the electric field in the tissue, reaching its limiting value;

2) exponent n characterizes the sensitivity of the plant tissue to damage and, by its value, it can be concluded: what tissues and which plant objects are more sensitive to electropulse damage, and which are less sensitive;

3) for reliable, irreversible damage to plant tissues of plant-derived objects, it is necessary to create sufficient electric field strength for the planned technological purposes.

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