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INFLUENCE OF WATER POTENTIAL ON THE FAILURE OF POTATO TISSUE

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A b s t r a c t. This paper presents research on the influence of water potential of potato tuber tissue on the mechanical parameters and count sum of the acoustic emission signal. In the experiment method of acoustic emission have been used. The results obtained prove the influence of water potential on the formation and propagation of cracks in the plant tissue deformed with a constant velocity along the sample axis. It has been observed that an increase in water potential causes a decrease in the compressive strength, maximal strain, critical strain, critical stress and an increase in the total count sum.

K e y w o r d s: acoustic emission, water potential, potato tissue

INTRODUCTION

Plant material is subjected to external forces during the whole production process. The action of external mechanical factors is manifested in the micro damages that cause plant browning and lower the quality of the whole yield. For these reasons intensive studies on the mechanical properties of plant materials have been carried out for many years [1,2,5]. Determination of the mechanical conditions for the formation of micro cracks is especially important in the case of this type of material [3,4, 6,10,11].

Plant tissue has a very complex structure. Each element in this structure exerts a certain influence on the mechanical properties of the tissue. Cellular liquids are one of these elements. They are sustained in the cells of the plant tissue under a certain pressure called internal pressure. Any changes in the internal pressure cause changes in the mechanical parameters of the cell, and hence the whole tissue [12,13,14,15].

When plant tissue is compressed, each of the cells takes over part of external loading. Nilson et al. stated that the following processes take place [13]: 1) cells change their shape, 2) tension in the cell walls increases due to the increase in the ratio between the surface of the cell walls and their volume, 3) turgor pressure increases, 4) intracellular liquids flow out of the cell with the speed related to the rate of loading and permeability of plasmalemma.

Cell walls are basic construction elements responsible for the strength of the whole tissue [6,14,15]. Tissue failure due to high cellular adhesion occurs through the cracking of cell walls [17]. If we continue deformation of the cell, the tensile stresses in the cell walls will increase and in consequence cracking of the tissue.

The method that enables studies on the processes of cracking that occur in the deformed material is the method of acoustic emission (called the AE method) [9,16]. The studies showed that this method allows for the determination of the mechanical conditions for the crack formation and then observations of their propagation in the plant tissue that are generated as a result of external forces [7,8,18].

The aim of the article is to present the results of studies on the influence of water potential on the parameters of the acoustic emission signal and mechanical parameters of the potato tuber tissue.

MATERIALS AND METHODS

The present experiment has been carried out for the potato variety Panda. The study material was bred in the Institute of Plant Breeding and Acclimatisation in Jadwisin. Potatoes ware collected in September, 1998 and stored during one month in the controlled conditions: 6 ^{o}C, 90.95 % humidity.

Cylindrical samples with the diameter of 10mm were cut out of the outer core by means of a steel cork drill along the longer diameter of the potato tuber. Next, the cylinders with similar height of about 30 mm were placed in 200 ml of one the mannitol concentrations with the following water potentials: -0.3, -0.45, -0.6, -0.9, -1.2, -1.5 MPa. Water potential of the man- nitol solutions was measured by means of a psychometric chamber C-52 and micro voltmeter HR-33. The samples were left in the solutions till the system reached the state of balance for 20±0.3 h [13]. The water potential of potato tissue will reach the value close to the initial value of the mannitol water potential. It is difficult to state exactly the value of turgor pressure for given water potential, since water transportation in the plant is an active process. For that reason in the further parts of the article the term water potential will be used for quantitative analyses, whereas in the qualitative considerations - the term turgor pressure will be used.

After that, samples were cut out by means of a knife with two parallel blades to the height of 5 mm. Compression tests were carried out by means of a Lloyd LRX testing machine. The samples were compressed with a constant velocity of 0.33 mm s^{-1} along the cylinder axis. Forty repetitions were carried out for each water potentials. In the experiment the stress in the function of strain were recorded. Mechanical parameters such as sample compressive strength, maximal strain, critical stress and critical strain were used for the analysis (Fig. 1). Sample compressive strength was defined as the maximal stress or the stress at which an increase in the strain did not cause any further increase of stress (beginning of the plateau) or a momentary, observable decrease in the stress. Maximal strain was defined as strain for the strength of the sample. Critical strain and critical stress were defined as the strain and the stress at which first AE counts were recorded.

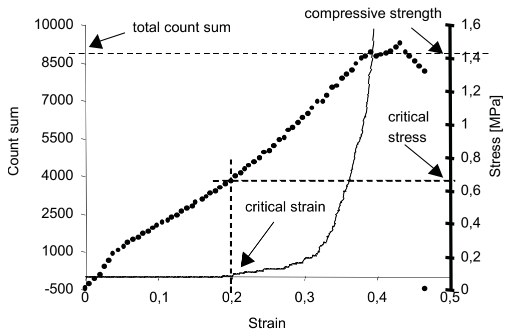

Fig. 1. The stress-strain curve (wide line) and the count sum - strain curve (narrow line) recorded in the experiment.

Acoustic emission

The term acoustic emission (AE) is used for the phenomenon of elastic waves generation and propagation as a result of release of the stored inner energy. As a result of turgor pressure in the plant tissue, there is a certain initial and heterogeneous distribution of stresses in it (Fig. 2). An external force acting on it will change this distribution. If the local stress exceeds the critical stress for the cell wall, then the process of plant tissue cracking will start. Part of the energy released in this process is emitted in the form of elastic waves that are called the acoustic emission signal (AE signals). The frequency range of this signal is from 10 kHz to 1000 kHz. The AE signal propagates from the source to the material surface where it can be recorded by suitable transducers, i.e., piezoelectric. The most frequently used parameter of the acoustic emission signal is the count sum that is determined by summing up the number of times

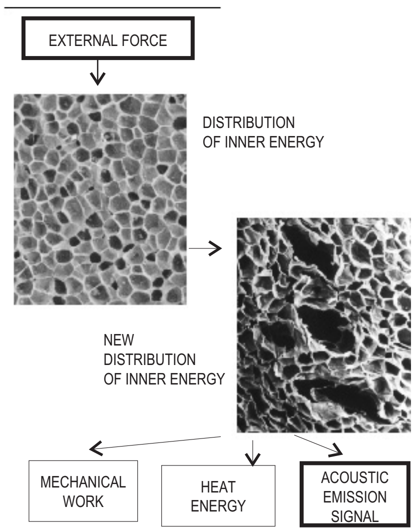

Fig. 2. The generation of the acoustic emission signal in the plant tissue subjected to external forces.

when the assumed voltage level (called the discrimination level) has been exceeded by the EA signal amplitude in a given time period [8,14].

In the present experiment, a wide-band piezoelectric sensor type WD (Physical Acoustic Corp., USA) with high sensitivity in a wide range of frequencies (25 kHz to 1000 kHz) has been used for the recording of the acoustic emission signal. Due to small sample sizes and high deformations of the plant tissues, the AE sensor is fixed to the plate of the stress machine exactly in the sample axis as can be seen in Fig. 3. This way of connecting eliminates sample friction against the sensor front but at the same time is ensures satisfactory good "acoustic connection". At the bond of sample - plate material (potato tissue - steel) the AE signal goes from the material with lower density to the material with higher density. Hence signal damping and distortion is not big. After leaving the AE sensor, the electric signal is amplified in the preamplifier (40 dB) situated in the close vicinity of the sensor. Then the signal is filtered and amplified again in the Acoustic Emission Analyser Type EA 100 [16]. The EA 100 Analyser transforms the AE signal into the form of counts recorded in the chosen time period (0.01 s). In the present experiment the recording of counts was carried out to the moment the sample reached the stress value equal to the sample compressive strength. The number of all the cunts recorded up to that moment was defined as the total count sum.

The measuring set applied for the present experiment allows for the simultaneous recording of the mechanical parameters mentioned above and the count sum of the acoustic emission signal.

RESULTS AND DISCUSSION

The results obtained in the present study prove that changes in the turgor pressure of potato tissue cause changes both in the mechanical

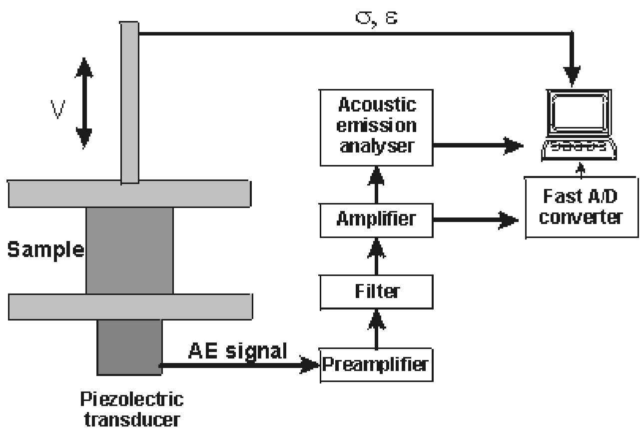

Fig. 3. The measuring system used in the experiment.

parameters and the total count sum. The average values of tissue compressive strength, maximal strain, critical stress and strain and total count sum together with their significant level (α= 0.05) obtained for different water potentials have been presented in Table 1.

10400 with coefficient of linear regression = 0.961. Considering the sample size used for the present experiment, i.e., (10 x 5 mm) the total count sum ranges from about 2500 (the minimal turgor pressure) to about 10 000 (the maximal turgor pressure).

T a b l e 1. Mean mechanical parameters and mean total count sum of AE signal for potato tuber var. Panda as a function of water potential (lest significant differences in 0.05 confidence level in brackets)

Water potential Ψ (MPa)	Compressive strength R (MPa)	Maximal strain ε_m	Critical stress R_c (MPa)	Critical strain ε_m	Total count sum ΣN
1	2	3	4	5	6
-0.3	1.42 (±0.04)	0.34 (±0.005)	0.65 (±0.02)	0.18 (±0.006)	9537 (±220)
-0.45	1.66 (±0.05)	0.36 (±0.005)	0.77 (±0.04)	0.21 (±0.006)	7641 (±300)
-0.6	1.70 (±0.03)	0.37 (±0.004)	0.81 (±0.03)	0.25 (±0.01)	6853 (±340)
-0.9	1.94 (±0.03)	0.39 (±0.004)	0.94 (±0.03)	0.29 (±0.01)	4995 (±240)
-1.2	2.36 (±0.08)	0.42 (±0.006)	1.31 (±0.07)	0.36 (±0.01)	4326 (±280)
-1.5	2.54 (±0.08)	0.44 (±0.006)	1.58 (±0.07)	0.38 (±0.01)	2464 (±110)

Increase in the water potential causes decrease in critical strain and critical stress (columns 4 and 5 in Table 1). It means that turgor pressure causes changes in the mechanical parameters at which the process of tissue destruction starts. The results obtained show that changes in turgor pressure can increase critical strain and critical stress by even over 100%.

The results of the present experiment prove that an increase in the water potential of potato tuber cause a linear decrease in the sample compressive strength and the maximal strain (columns 2 and 3 in Table 1). Relation between the tissue compressive strength and the value of water potential can be described by equation: $R = - 0.93\ \Psi + 1.17$ (coefficient of linear regression has the value of 0.981). Relation between the tissue maximal strain and the value of water potential can be described by equation: $\varepsilon_m = - 0.08\ \Psi + 0.32$ (coefficient of linear regression has the value of 0.992).

Shapes of count sum - strain curves obtained in the experiment are connected with turgor pressure (Fig. 4). Changes in the turgor pressure of the tissue cause changes in the total count sum. Alongside the increase in the water potential of the tissue the total count sum increases almost linearly (in the range of water potential: from -0.3 MPa to -1.5 MPa): $\Sigma N = 5384\ \Psi +$

Most often it is assumed that cells of the plant tissues have the shape of tetraidecachedron (with 14 walls) or a sphere [13,14]. These bodies have relatively the highest ratio volume to surface. Due to cell turgidity, the cell walls are initially tensed. Higher turgor pressure has results in higher tension in the cell walls. In the situation where the cell with initial turgor is compressed, the ratio of volume to the cell surface decreases. It means that the cell walls are additionally stretched. Hence, cell strain or stress at which cell wall will cracks, is lower for

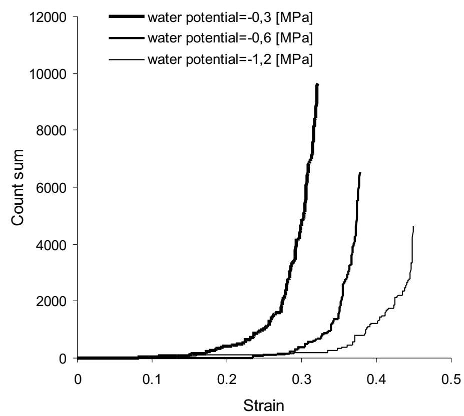

Fig. 4. The count sum in the function of the strain obtained for different water potentials.

higher value initial turgor pressure. That is how we one can explain the decrease in the value of critical strain and critical stress when the water potential of the potato tuber tissue increases (Table 1).

At a given strain (higher than the critical strain), the number of cracked cell walls depends on the initial turgor pressure and it will be higher for higher initial turgor pressure. Applying great simplification, we can assume that the plant tissue is mechanically weakened when some walls get cracked. Hence, we can suspect that the plant tissue with higher initial turgor pressure will achieve the state of strength at lower stress and strain (Table 1).

The structure of a plant tissue is very heterogeneous hence the processes of crack formations and crack propagation are of a stochastic character. This fact makes interpretation of results difficult and is the reason for the relatively high values of significant level (α=0.05) in the total count sum.

Mechanical reactions in the plant tissue are of a very complex nature. Individual processes (increase of turgor pressure during compression, outflow of intracellular liquid from the cell) take place simultaneously, and the results obtained are the resultant of all the processes involved. What is more, plant microstructure is very complicated. Despite numerous research studies on the mechanical properties, the processes that take place in plant tissues under external loading have not been recognised enough. There is no generally accepted theoretical model that would describe mechanical properties of plant tissues. Hence the interpretation of results presented in this study is greatly simplified.

In the present study an attempt to supplement the existing knowledge on the mechanical properties of plant tissues. The methods of acoustic emission applied to the plant materials show that the processes of cracking take place even at small deformations. The above results can be very useful in practice since the method of acoustic emission allows to establish mechanical conditions at which irreversible changes (in the form of cracks) of the plant materials take place.

CONCLUSIONS

Results of the studies on the influence of the water potential on the mechanical parameters and the parameters of the acoustic emission signal allow to formulate the following conclusions:

1. An increasing water potential of the potato tissue reduces the critical strain and the critical stress (the values at which the process of cracking starts),
2. The total count sum increases proportionally to the increase of water potential of potato tissue,
3. The compressive strength and the maximal strain of the potato tuber are a decreasing function of the water potential.

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