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METHOD OF ACOUSTIC EMISSION IN THE STUDIES OF CRACKING PROCESSES IN PLANT TISSUES

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ABSTRACT

As a result of plant tissue deformation irreversible physical processes that finally lead to the state of resistance, take place. One of these irreversible processes is cracking of the cell structure that occurs through cell wall breaking and losing cohesion in the layer of pectin lamella. As a result of these phenomena a signal of acoustic emission is emitted. In the present study the method of acoustic emission and its application in studying the processes of plant tissue cracking are described.

Key words: method of acoustic emission, cracking.

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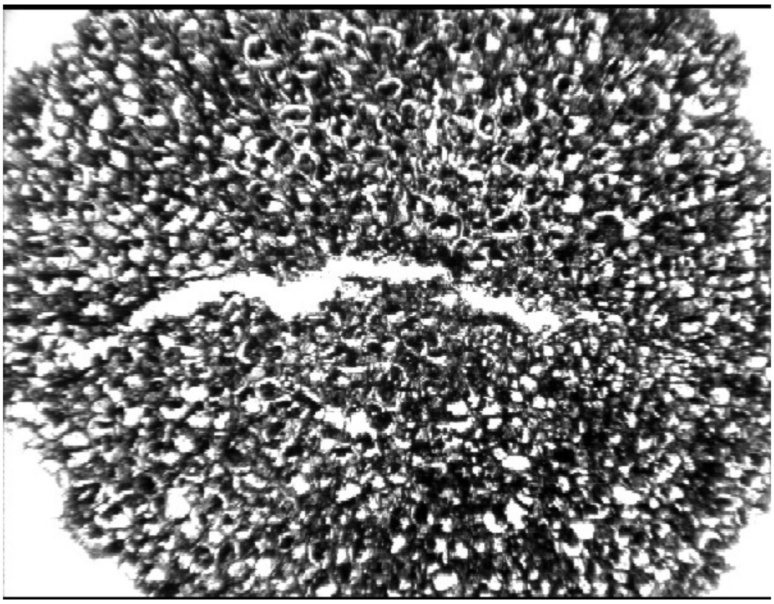
INTRODUCTION

Plant material is subjected to external loading during the whole production process. The impact of heavy agricultural machines during plant growth and storage causes external and internal mechanical damage. It leads to enormous losses in plant production. External mechanical factors are manifested in the generation of micro damages that cause damage to the whole yield and lowering of its quality. Hence, intense studies on the mechanical properties of plant materials have been carried out for many years [1, 3, 8, 9, 10, 11]. Determination of mechanical conditions for the generation of micro cracks in the plant tissue as a result of the stress applied and strain, is especially important.

Studies on the processes of plant tissue cracking are closely related to the studies on their mechanical properties, since both initiation and propagation of a crack depends on the stress distribution in the tissue [4]. Usually universal testing machines are used for the studies of mechanical properties as they allow for setting different deformation programs. The test result is obtained in a form of a relation between stress and strain [1, 3, 8, 10]. In this method the cracking process is determined by the observation of the curve slopes. Mechanical failure of plant tissue is manifested as a sudden decrease in the plant stress or reaching a plateau by the stress-deformation curve. In material technology such a condition is called the material strength. In the case of plant tissue the material strength results from the processes of structure cracking. Their scale is large enough to cause a clear change in the slope angle of the stress-strain curve (fig. 1).

Fig. 1. Crack of potato tissue after reaching the sample strength



Chemical processes that lead to plant tissue rotting (e.g. black spots) are most often caused by the cracking of half-permeable plasmalemma film and the reaction of intracellular enzymes with oxygen [2, 13]. Hence, it is very important to learn the mechanical conditions of the cell wall cracking at the earliest possible stage of deformation. Cracking of this scale has little influence on the values of stress for the whole sample and cannot be registered by means of universal testing machines.

The aim of the paper is to present the method of acoustic emission and its application in studying the processes of plant tissue cracking.

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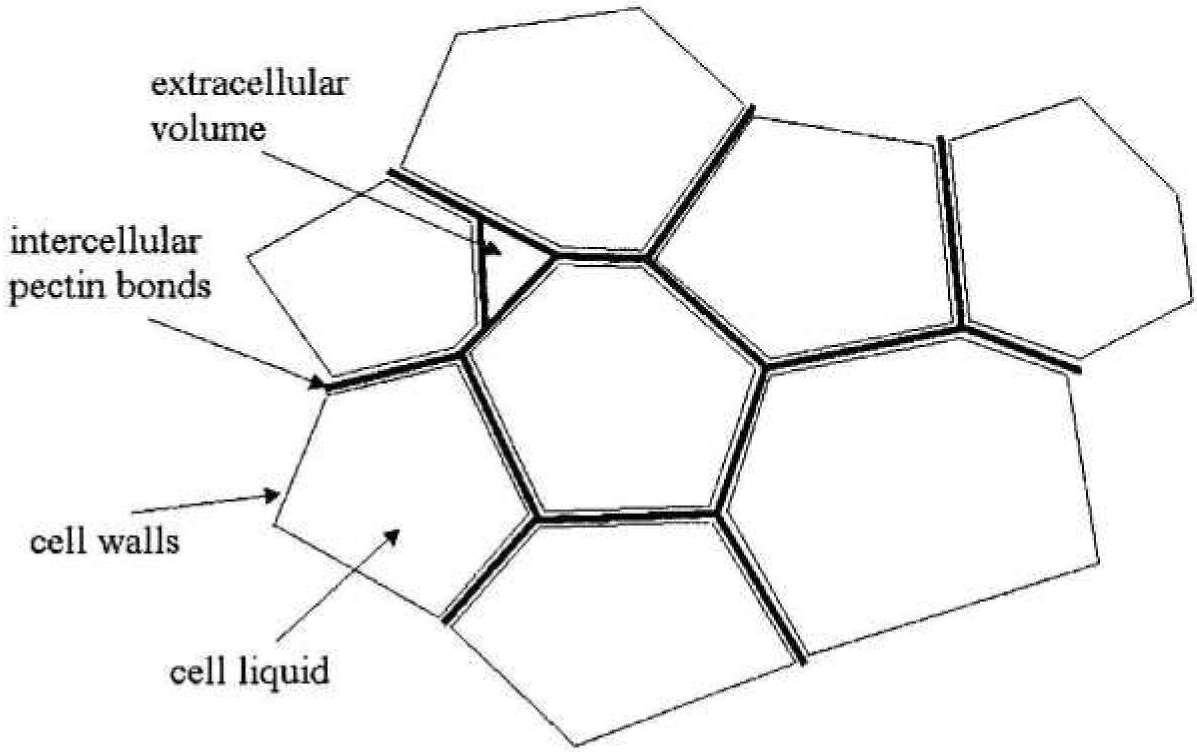
Acoustic emission in plant materials

The term "acoustic emission" (EA) is used to describe the phenomenon of generation and propagation of elastic waves as a result of sudden release of energy stored at a certain point of the studied medium. Energy emitted in this process is changed into heat, mechanical work and a small part is emitted as elastic waves. These elastic waves are called an acoustic emission signal (AE signal). On the other hand, the source of the acoustic emission signal is defined as a location or structural element that emits the EA signal.

Sources of the acoustic emission signal in plant tissue that are generated under a load of external forces should be searched among their structural elements [4, 5, 6].

Generally speaking, plant tissue consists of three basic components: a) parenchyma cells with thin walls filled with intracellular liquids, b) intracellular pectin lamellae that joining elements for the cells, c) intracellular spaces that can contain liquid or gas (fig. 2).

Fig. 2. Scheme of plant tissue



Each plant cell consists of cell walls that surround cytoplasm, nucleus and vacuole, which contains about 90% of cellular fluids. Cytoplasm is surrounded by a half-permeable film called plasmalemma. Plant cells are in the shape of polyhedron that results from the intracellular pressure called turgor.

Cell walls are the basic structures that are responsible for the strength of the whole tissue [4, 10, 11]. External loading causes changes in stress distribution of structural elements, e.g. if an external force is strong enough, cell walls will crack. Plant tissue is of a very complex structure. Cell walls are of varied strength and distribution of stress. If an external force is applied, a new distribution of stress occurs. The process of cracking will develop in relation to the structural parameters of the studied material, tissue turgor and the character of external influences (e.g. strain rate).

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Plant cells are joined together with pectin lamellae. These elements are plastic and allow the cells to slowly change their orientation and position during deformation process [10]. When the force components are of a high value, the neighbouring cells can change orientation without cracking the cell walls. The existence of intracellular volumes strongly influences changes in the cell orientation and position. The intracellular volumes can be filled with liquid or gas, however their influence on the rheological properties and on the cracking processes has not been fully recognised as yet.

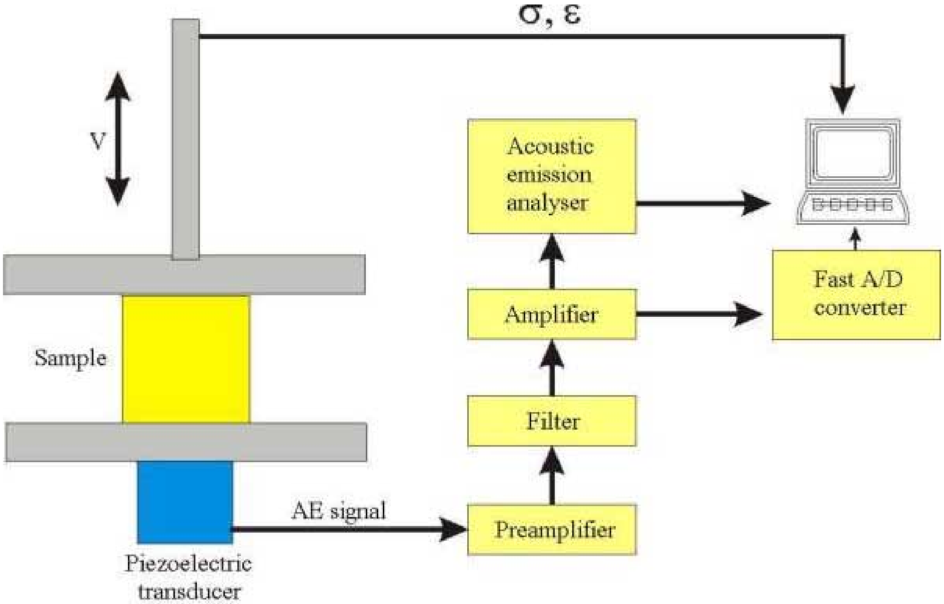
In the processes mentioned above an acoustic emission signal can be emitted which propagates to the sample surface, where it can be recorded.

MEASURING SYSTEM

As has already been mentioned above, the signal of acoustic emission is generated in the plant tissue that is subjected to external forces as a result of the cracking of its structure. In practice, such conditions can be generated when samples are compressed in the jaws of the testing machine.
A diagram of the apparatus used for examining the cracking processes in plant tissue is presented in fig. 3. A modern one-column testing machine Lloyd LRX was used for studying the mechanical properties and forces that participate in the process of plant tissue cracking. The machine allows to carry out compression tests with a chosen velocity from 0.1 mm/min to 1000 mm/min. The tests proved that in the full range of deformation velocity, the machine applied does not create any disturbances in the recorded EA signal generated in the compressed material.

A wide-band piezoelectric sensor, type WD, was used for the recording of the acoustic emission signal with high-sensitivity in the frequency range from 25 kHz to 1 MHz. The transducer was fixed to the lower jaw of the testing machine exactly in the sample axis (fig. 3). This way of fixing allowed for the elimination of any noise generated by friction between the transducer and the deformed material. At the border of a sample-jaw material (potato tissue-steel), the EA signal goes from the material of lower density to the material with higher density; damping and deformation of the signal is then low.

Fig. 3. Block diagram of the measuring system, where V - strain rate, sigma - stress, epsilon - strain



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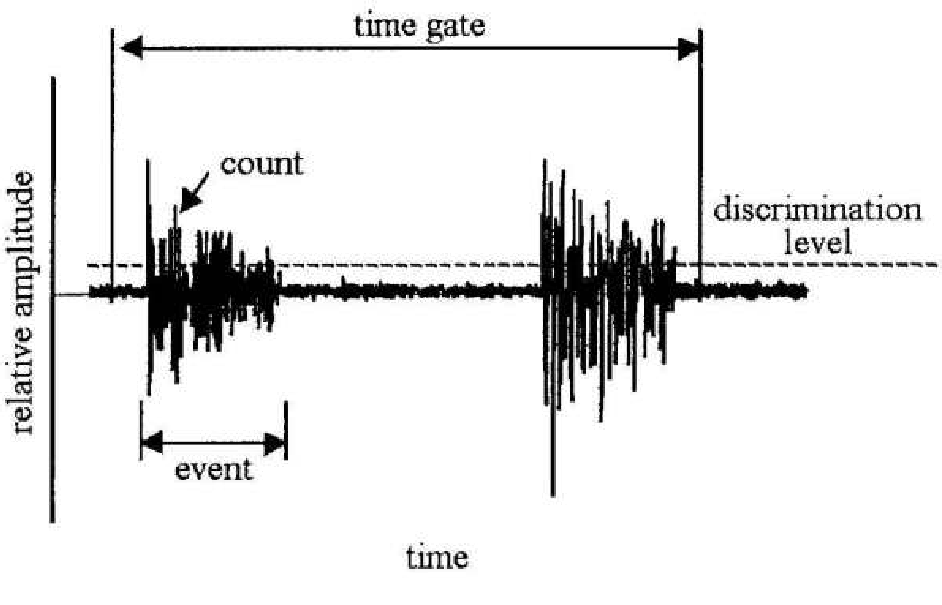
In order to analyse and register the signal of acoustic emission, EA 100 set was applied. The set consists of a pre-amplifier (40dB) with an upper valve (25 kHz), an amplifier with adjustable gain and EA 100 analyser. The set is supplemented with a high speed transducer card A/D that allows for the recording of 250 micro s time samples with the frequency of 2.5 MHz.

The EA signal can be analysed in two independent measuring ways. In one of them, the voltage signal after amplification is recorded with high frequency (2.5 MHz) as the relation between amplitude and time. The aim of such an analysis it to characterise the source of the EA signal. The analysis of the AE signal as the amplitude-time relation requires an in-depth knowledge of wave propagation in the studied medium, the function of the transition 'material-transducer' and the disturbance caused by the measuring gauge itself. These problems are usually very difficult to examine and hence, applicability of this type of analysis is limited [7, 12].

The second method of analysing the EA signal is one based on the transformation of the time signals to the form of descriptors. In order to obtain information on the source of the EA signal certain characteristic parameters are chosen and studied in relation to time and external factors. These parameters are recorded in time gates. If a certain threshold is established for the amplitude of the received signal, called a discrimination threshold, then every time the amplitude goes above this signal it is recorded as one count. Groups of the AE signal with the characteristics of a damped sinusoid curve are called events (fig. 4). The number of counts and the number of events recorded in time gates are called count rate and event rate. Besides the two parameters mentioned above, other parameters based on the transformations of time or spectrum relations of the EA signal are also used. Detailed definitions and descriptions of the EA signal descriptors can be found in literature [7, 12].

Fig. 4. Determination of descriptors of acoustic emission (counts and events)



A very useful method of analysing the signal of acoustic emission is by presenting the above parameters in a summed up form (sum counts, or sum events). Sum counts and sum events can be presented in a function of an external parameter, i.e. deformation, stress, or temperature. This type of relation gives information on the processes that take place in the sources of the EA signal of the studied structures.

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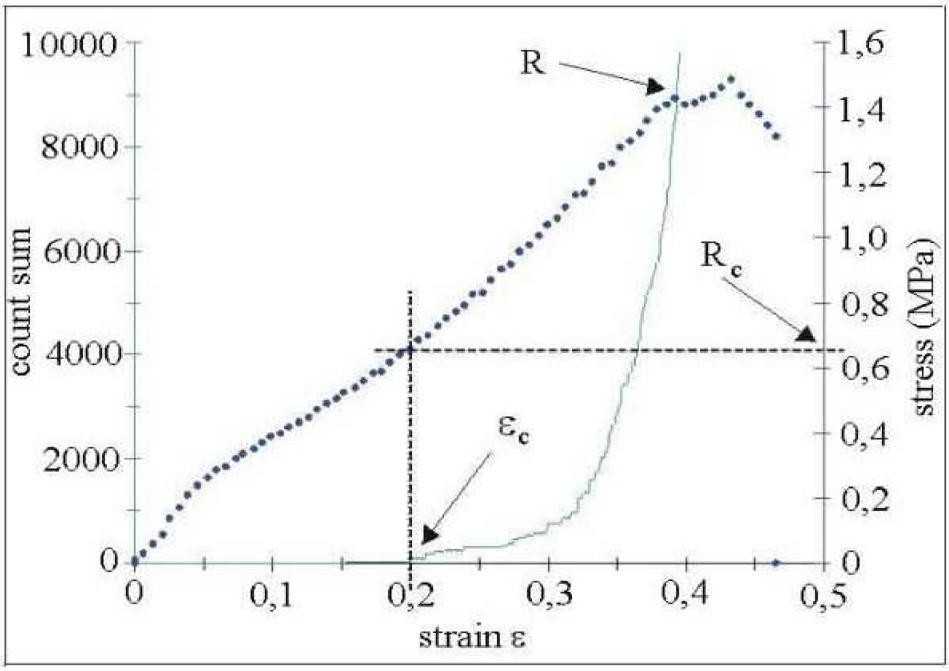
Configuration of the apparatus presented in fig. 3 enables simultaneous recording of the following physical parameters: sample strain or its stress, sum counts, sum events, peak value of the EA signal and 140 time samples of the EA signal with the frequency of 2.5 MHz.

EA SIGNAL IN POTATO TISSUE

The method of acoustic emission and the apparatus described in the present work allow to carry out studies on the influence of various factors on the cracking processes in plant tissue. An analysis of relation between the parameters of the EA signal and a chosen mechanical parameter is especially useful (fig. 5). These types of relations allow to determine the mechanical conditions that start the cracking process in the studied plant material. They enable evaluation of the scale of the cracking processes through the observation of the slope of the studied curve, e.g. sum counts – strain.

Deformation of the cylindrical sample of potato tuber proved that the counts of the EA signal are recorded at relatively small values of deformation and sample stress when compared to the sample compressive strength R (fig. 5) [5, 6]. The above studies confirm the hypothesis that the processes of plant tissue cracking take place gradually, and the status of sample strength results from a slow propagation of cracks [4]. The structure cracking occurs when stress reaches the strength of some structural elements, e.g. strength of the cell wall. This point on the stress-strain curve corresponds to the first EA counts and can be defined as critical stress R_c and critical strain **epsilon** $_c$ [6].

Fig. 5. Characteristics obtained with the method of acoustic emission, where: R-compressive strength,
Rc - critical stress, epsilon $_c$ **- critical strain**



In order to check how useful the method of acoustic emission is for the studies of plant tissue cracking, a number of tests were carried out [6, 7, 14].

Haman et. al. conducted compression tests on potato tissue with different turgor pressure [6]. The turgor of potato was changed by placing the samples in mannitol solution with different concentrations. Acoustic emission method was used in order to obtain the critical stress and

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the critical strain. The studies showed that changes in the water potential of potato tissue cause changes both in the critical stress and the critical strain (fig. 6 and 7, respectively) [6]. Increase in the turgor of potato tissue causes decrease in the critical strain and stress. The results comply with the model proposed by Pitt [10, 11].

Fig. 6. Critical stress vs. water potential for varieties Panda and Bila

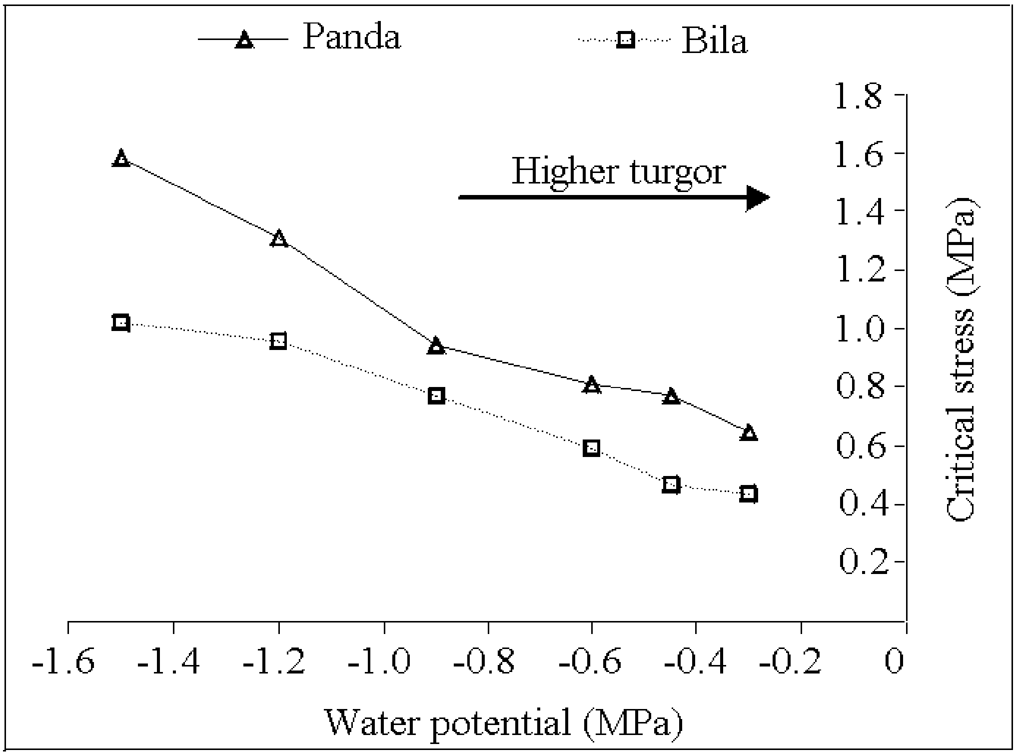
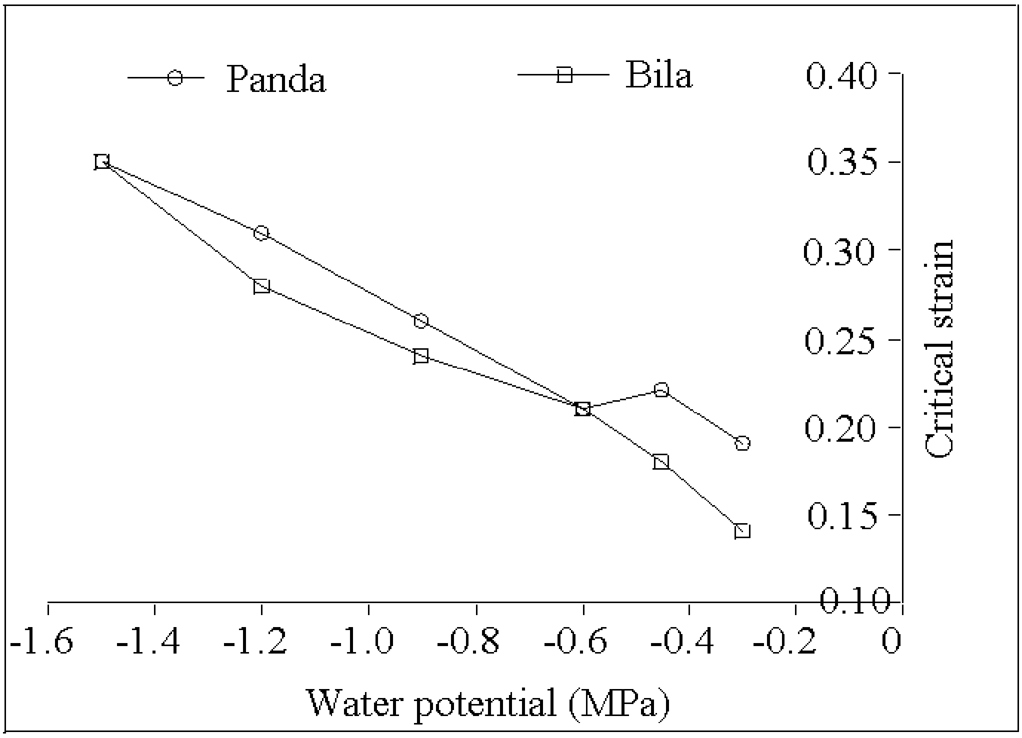


Fig. 7. Critical strain as a function of water potential for varieties Panda and Bila



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Other materials parameters were considered in investigating potato cracking processes. Cells parameters are one of the most important elements that determine the strength of the plant tissue [4, 10, 11]. In order to check the influence of the type of tissue on the critical stress and the critical strain compression tests were carried out for inner core and outer core of potato tissue (fig. 8) [5]. The experiment showed that critical states are different for both types of tissue: the outer core tissue and the inner core tissue of potato tuber (table 1). The cracking of the inner core tissue occurs at lower values of stress and strain than for the outer core. The results show that the compressive strength is higher for the inner core (in opposite to critical values) than for the outer core. It means that macro – strength of the inner core is higher but micro – strength is lower than for the outer core.

Fig. 8. Cross section of potato tuber: a - sample of outer core, b - sample of inner core

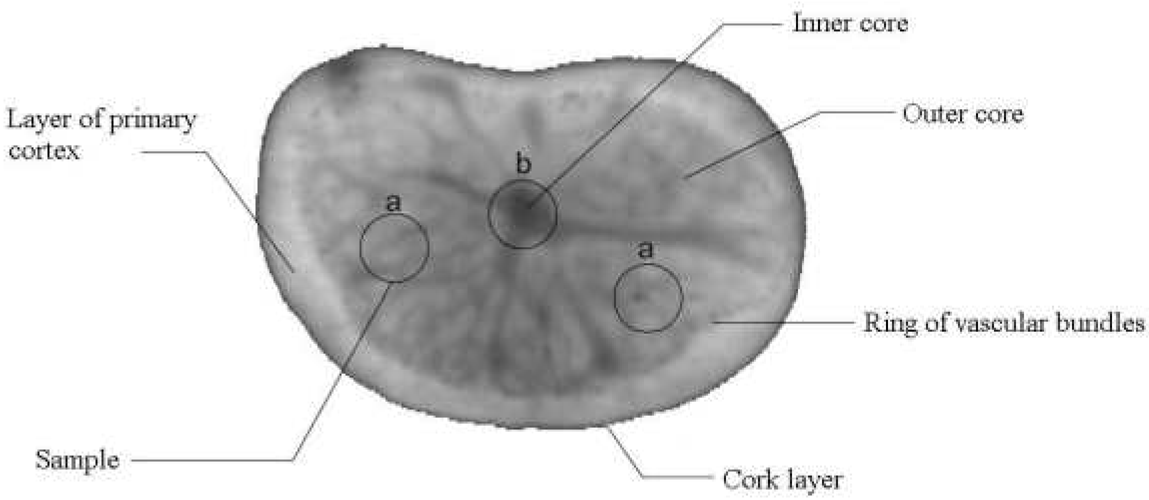

Table 1. Mechanical parameters of the inner core and the outer core of Triada variety; standard deviations are given in brackets

Place of sampling	Critical strain **epsilon$_c$**	Critical stress R_c (MPa)	Compressive strength R (MPa)
Inner core	0,10 (0,05)	0,38 (0,20)	2,24 (0,20)
Outer core	0,21 (0,04)	0,69 (0,15)	1,71 (0,10)

A detailed description of cracking processes in plant tissue requires supplementing the studies carried out with the application of the acoustic emission method with microscopic studies. However, it is extremely difficult to study theses phenomena with microscopic methods due to difficulties in localizing the source of the EA signal, closing of the broken elements when the applied force has been withdrawn, stochastic character of the cracking processes, no theoretical indications as to the localisation of the broken elements (no mechanics of structure cracking in the case of structures such as plant tissue is available).

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CONCLUSIONS

The study results gathered by means of the method of acoustic emission showed how useful this method is for studying the processes of cracking in plant tissue. The results obtained in this way supplement measurements of mechanical properties of these types of materials with new data that are very difficult to obtain by means of other methods. Data on the cracking processes can become very useful in agricultural practice and in working out theoretical models of deformation processes in plant tissue.

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