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Influence of turgor and cell size on the cracking of potato tissue

K. Konstankiewicz and A. Zdunek*

Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, P.O. Box 201, 20-290 Lublin 27, Poland

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A b s t r a c t. Mechanical properties of plant tissue are determined by their intracellular pressure and cellular structure. The aim of the presented paper is to study influence of turgor and cell size on the process of potato tissue cracking. The method of acoustic emission has been used to determine failure conditions as the critical strain and the critical stress for potato tuber tissue with different turgor and cell size distribution. Increase in turgor causes decrease in the compressive strength, critical strain and stress. Higher contributions of smaller cells cause an increase of the compressive strength, but smaller resistance to micro-damage.

K e y w o r d s: plants, failure, mechanical properties

INTRODUCTION

Plant material is subjected to external forces during the whole production process. The action of external mechanical factors is manifested by micro-damages that cause plant browning and lower yield quality. Hence, intense studies on the mechanical properties of plant materials have been carried out for many years. Determination of the mechanical conditions for the formation of micro-cracks is especially important in the case of plant material. Breaking of cell membranes causes chemical reactions which are direct reason for browning of the tissue [2,3,8,9].

In the compressed plant material the following basic processes take place: changes in cell shapes, tension increases in cell walls and their cracking, debonding of the cells, filtration of intracellular liquids through the cell walls [6]. For certain values of strain the sample reaches the highest value of the stress which is called a compressive strength - *R*. The structure of the plant tissue is very heterogeneous so failure of the tissue can occur at lower stresses than the sample strength [2]. Cell walls are basic construction elements that are responsible for the strength of the whole tissue [2,3]. As a result of turgor pressure in plant tissue, there is a certain initial and heterogeneous distribution of tension in its cell walls. An external force acting on the plant tissue will change this distribution. If a local tension exceeds the critical tension for the cell wall, then the process of plant tissue cracking will start [2,7,8]. Similarly, if stress in the middle - lamellas is higher than the critical stress, debonding of the cells and re-organisation of the whole structure will take place [7,8]. Zdunek and Konstankiewicz [10] showed that a passive method of acoustic emission (the so-called AE method) can be used for studies on the cracking processes that occur in the deformed plant tissue. They used the acoustic emission method to define mechanical conditions when the failure starts as a critical stress - R_c and a critical strain - ε_c [5]. Experiment carried out on potato tissue with different water potentials showed that increase of turgor pressure causes decrease of the critical values and strength of the Panda variety sample [3].

Potato parenchyma consists of various types of tissue, i.e., cork layer, layer of primary cortex, ring of vascular bundles, outer core, and inner core. They fulfil specific functions, both physiological and mechanical. Many mechanical models of plant tissue assume that mechanical properties are determined by structural parameters and intracellular pressure [2,6-8]. However, the influence of the place of sampling, and hence the influence of the structural parameters (e.g., cell size) of potato parenchyma on its mechanical properties is still not well understood.

The aim of the presented paper is to study influence of turgor and cell size on the process of potato tissue cracking.

*Corresponding author e-mail: konst@demeter.ipan.lublin.pl

MATERIALS AND METHODS

Influence of turgor on the potato tissue failure

In the first part of the experiment, samples of potato varieties Panda and Bila were used. Procedure of turgor pressure changing is presented in paper by Haman *et al*. [3]. Cylindrical samples with a diameter of 10 mm and similar height of about 30 mm were placed in 200 ml of mannitol solutions with different concentrations. 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 [8]. Then they were cut up to the height of a 5 mm cylinder and subjected to mechanical tests. The tests were carried out on 40 samples for each turgor.

Influence of cell size on the potato tissue failure

The tests were done for two types of potato tissue of Triada variety: inner core and outer core. Studies were carried out on 40 samples for each series. The samples had a cylindrical shape with the height of 5 mm and diameter of 5 mm. Size of the sample was chosen in order to allow sampling the most homogeneous material. This is especially difficult in the case of inner core which occupies only a small volume in relation to the total tuber volume. Samples of inner core and outer core were nex t subjected to mechanical tests.

In order to obtain structural parameters that describe cell size a confocal optic microscope (objective plane of 10/0.25) was used [4]. Images of cross-sections of the cell structure were taken directly after fresh tissue of the inner core and outer core had been cut out. Next, 168 pictures were taken for each type of tissue, as in Fig. 1A. The pictures were not overlapping. Then, cell walls were marked by means of Corel Draw 8.0 (Fig. 1B). Binary images of the tissue structure were subjected to quantitative analysis by means of Aphelion software. Cell's area and maximal Feret's diameter of the cell cross-sections were chosen as parameters of cell sizes.

Method of acoustic emission and mechanical tests

The term acoustic emission (EA) is used for the phenomenon of generation and propagation of elastic waves as a result of release of stored inner energy. Part of the energy released in these processes and emitted in the form of elastic waves, is called a signal of acoustic emission (AE signal). The AE signal propagates from the source to the material surface where it can be recorded by a suitable transducer, i.e., a piezoelectric one.

The measuring system used in the experiment consists of universal testing machine - Lloyd LRX and Acoustic Emission Analyser EA 100 with wide-band piezoelectric sensor type WD (Physical Acoustic Corp., USA). The measuring set allows for the simultaneous recording of mechanical characteristics as stress-strain curves and the acoustic emission signal. This measuring method allows to determine the critical strain and the critical stress (Fig. 2) [3,5].

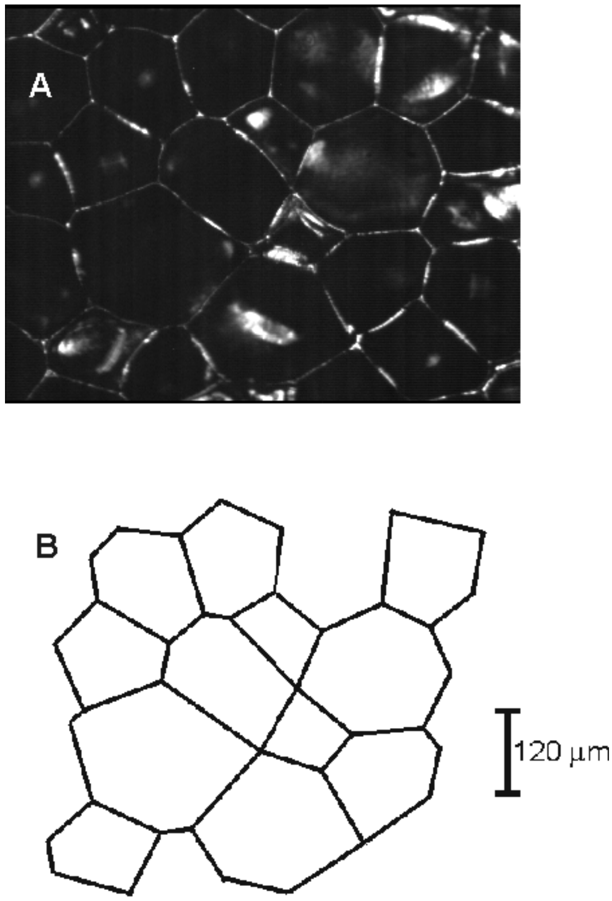

Fig. 1. Image of the potato tissue cross-section (A). Skeleton of the cell structure (B).

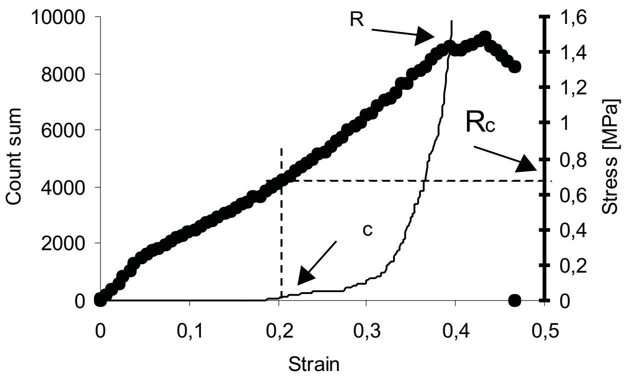

Fig. 2. Method of obtaining mechanical parameters: R_c - the critical stress, ε_c - the critical strain, R - the compressive strength. The stress - strain curve is shown as wide line. The count sum-strain curve is shown as thin line.

Samples were compressed with constant rate of $0.33 \cdot 10^{-3}$ m s^{-1} along the cylinder axis. Mechanical values such as sample compressive strength, critical stress, and critical strain were used for the analysis (Fig. 2). The 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 part) or a momentary observable decrease in the stress. The critical strain and the critical stress were defined as the strain and the stress at which the first AE counts were recorded.

RESULTS AND DISCUSSION

The results obtained in the experiment prove that the changes in the turgor of potato tissue cause changes in the tissue compressive strength, the critical strain, and also the critical stress in the case of both potato varieties. These mean values for both potato varieties as a function of water potential levels are presented in Figs 3 and 4.

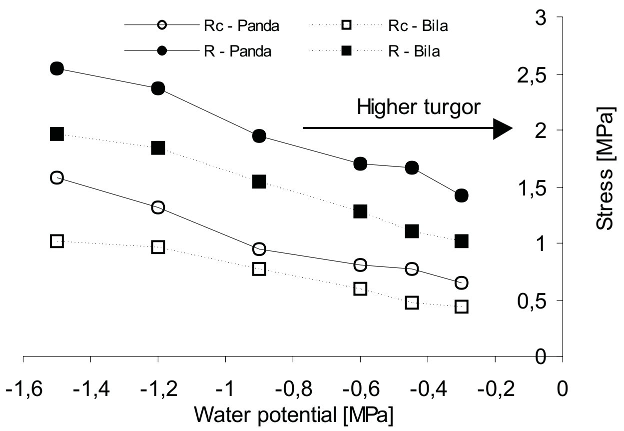

Fig. 3. The compressive strength R and the critical stress R_c vs. the water potential for varieties Panda and Bila.

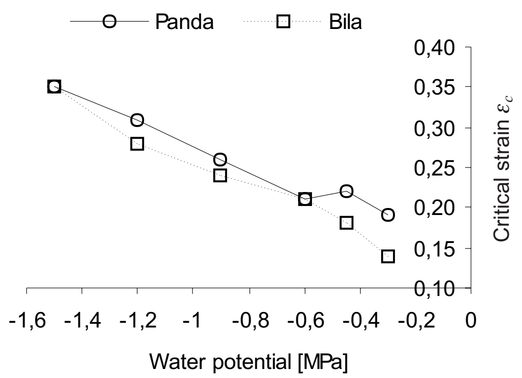

Fig. 4. The critical strain ε_c as a function of the water potential for varieties Panda and Bila.

Cell walls are the main elements of plant tissue construction. Their strength exerts major influence on the strength of the whole cell structure. Strength of the cell wall is a parameter that characterizes the material of which the wall is made. This parameter does not depend on the intercellular pressure. However, an increase in the turgor causes an increase in the initial tension of the cell walls. When plant tissue is compressed, intercellular pressure increases together with the tension in the cell walls. Hence, it can be expected that energy required for cracking cell walls will be smaller for higher values of the cell turgor. This, in turn, implies a decrease in the critical strain, the critical stress and the compressive strength of the potato tissue observed with the increase of its turgor (Figs 3 and 4). The above results agree with the expectations of the model proposed by Pitt [7] and Pitt and Chen [8].

The critical strain, the critical stress and compressive strength of inner and outer core are presented in Table 1. Distribution of the cell areas and the maximal Feret's diameter is presented in Figs 5 and 6, respectively.

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 ε_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 shift of the curves for the inner core towards lower values of the studied parameter can be clearly seen in the distribution curves. Character of the changes are the same for each parameter. It proves that, in general, tissue of the inner core consists of smaller cells than in the outer core. This result contradicts the known fact that the inner core contains of dry mass lower by about 7% than the outer core [1]. However, in the structural analysis of the pictures obtained from the confocal microscope, only the cell walls are taken into consideration, and other structural elements (e.g., starch) are neglected. Starch can be found in the inner core in small quantities when compared to the outer core. It is the reason for different results of the present experiment than given in literature.

Mechanical test with the application of the method of acoustic emission allows to find out that the tissue of the inner cores has lower values of the critical stress and strain but a higher the compressive strength. When distributions obtained for cell size of the studied tissue (Figs 5 and 6) are compared with the mechanical properties of potato tissue (Table 1), it can be concluded that there is a relation between cell size and mechanical properties of potato tissue. Higher contribution of smaller cells causes an increase in whole tissue resistance (higher value of the compressive strength), but smaller resistance to micro-damage (lower values of the critical stress and strain).

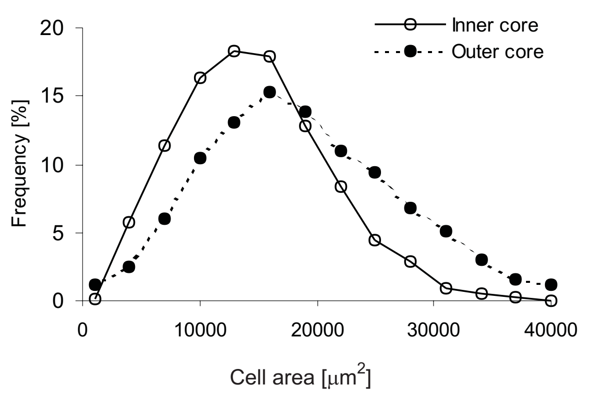

Fig. 5. Distribution of the cell areas for the inner core and the outer core of Triada variety.

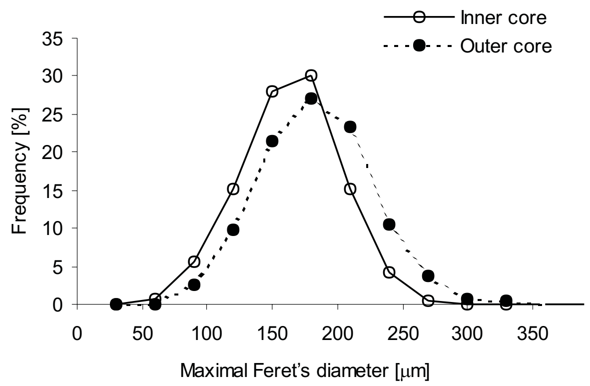

Fig. 6. Distribution of the maximal Feret's diameter for the inner core and the outer core of Triada variety.

CONCLUSIONS

The presented study results show that simultaneous recording of the stress-strain characteristics and the acoustic emission signal gives new information on the mechanical properties of plant tissues. It supplements the results in the form of the stress-strain curves with the information on the occurrence and intensity of the cracking processes.

The results of the mechanical test carried out by means of the acoustic emission method allows to draw the following conclusions:

- The mechanical conditions for crack formation depend on the tissue turgor. Increase in turgor causes decrease in the compressive strength, critical strain and stress.
- Higher contribution of smaller cells causes an increase in whole tissue resistance (higher value of the compressive strength), but smaller resistance to micro-damage (lower values of the critical stress and strain).
- The tissue of potato tuber cannot be treated as a uniform structure; there are clear differences in the mechanical properties of the inner and outer cores.

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