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Influence of structural parameters of potato tuber cells on their mechanical properties**

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A b s t r a c t. The present study concentrates on the influence of structural parameters of potato tuber tissue on its mechanical properties. Observations of the cell structure were carried out by an optical confocal microscope. Image analysis allowed obtaining parameters describing cell size and cell shape. Image analysis and compression test of the outer core of three potato varieties: Danusia, Kuba, Triada were carried out. Stress-strain curves were recorded in tests with constant rate 5 mm min^{-1}. It was found out that the parameters of the structure such as: cell area and cell perimeter, exert a significant influence on mechanical parameters, i.e., strength and modulus of elasticity. The present study did not confirm that there is a relation between cell shape and the mechanical parameters.

K e y w o r d s: parameters of cell structure, mechanical parameters, potato tuber

INTRODUCTION

Quality improvement of food products requires in-depth knowledge on the mechanical parameters of agricultural materials as fruits and vegetables, especially conditions at which these materials get damaged. Plants belong to the class of biological materials with complex structure with high susceptibility to mechanical damage. These damages cause irreversible changes in structure, colour, taste of the tissue and lower crop quality. Damages very often are not visible on the surface of fruits or vegetables and they are limited to small inner cracks. These cracks can lead to infections and biochemical changes that, in turn, result in material rotting during storage (Reeve, 1968).

One of the most common plant of the world is potato (10th position in respect to its plantation area). However, due to external and internal damage a considerable part of potato yield cannot be used in production (Zgórska, 1997). Intensive research work on the mechanical properties of potato tuber tissue have been carried our for many years (Finny and Hall, 1967; Nilson, 1958; Mohsenin, 1986). Basic mechanical parameters determined in these studies are: strength, and modulus of elasticity obtained by the analysis of relation between strain and stress. These parameters are most often studied at various turgor, temperature, storing methods, varieties, etc. (Shi *et al*. 1998; Haman *et al.* 2001; Nilson *et al.* 1958). However, due to technical difficulties, relations between mechanical parameters and the parameters of plant tissue microstructure have not been studied enough.

Each type of tissue has characteristic mechanical properties. In detailed analyses carried out by means of the acoustic emission, it was shown that the cracking processes are entirely different in the outer and inner core of potato tuber tissue (Haman *et al*. 1999). Konstankiewicz and Zdunek have obtained that inner core of potato tuber with smaller cells has higher strength in comparison to outer core with bigger cells (Konstankiewicz and Zdunek, 2001).

Konstankiewicz *et al*. (2001) have worked out method for the quantitative analysis of structural parameters of plant tissues. This method basis on images of plant tissue obtained by a confocal microscope that allows for the observations of objects in their natural state. Proposed procedure for image analysis is supported by computer software and it is especially useful for carrying out studies on a large number of samples that require statistical analysis. In the present work, above method for the quantitative analysis of structural parameters is applied to find out influence of the structural parameters of different varieties of potato on their mechanical properties.

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MATERIALS AND METHODS

In the present work three varieties of potato tuber (*Solanum tuberosum*): Danusia, Kuba, and Triada were used. The material was produced in the Potato Storing and Processing Plant of the Institute of Plant Acclimatisation in Jadwisin and harvested in 1999. The tubers were stored in controlled conditions (temperature 6°C and humidity 90-95%) for 3 months. Experiment was carried out in room conditions on samples cut out from the biggest part of the tuber - outer core. It allowed to cut out samples relatively homogenous.

In the experiment two cylindrical samples called 'sample 1' and 'sample 2' were cut out from each tuber (Fig. 1). First of them with the height of 5 mm and the diameter of 7 mm was used for determining mechanical properties of the tissue and the second with a height of 1 mm and a diameter of 7 mm was used for determining structural parameters. The samples were cut perpendicularly to stolon - apex axis of the tuber.

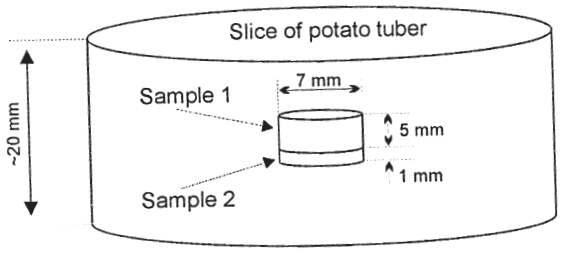

Fig. 1. Potato tuber sampling (unprepared sample).

Cell structure parameters

30 'samples 2' of each varieties were used for determining the structural parameters. Observations of the cell structure were carried out by means of an optical confocal microscope (Tandem Scanning Reflected Light Microscope - TSRLM). A Plan 10/0.25 lens with a magnification of about x20 was used. That allowed for observing from 10 to 15 full cells in one observation field (image). About 10-15 non-overlapping microscopic images were obtained for each 'samples 2'. Sample preparation and image analysis were carried out according to the procedure described by Konstankiewicz *et al*. (2001). The procedure allowed obtaining 2818 cells for Danusia, 4914 cells for Kuba and 5067 cells for Triada.

Analysis of microscopic images allowed obtaining geometrical parameters describing cross-sections of the cell structure of the potato tuber tissue: cell area, cell perimeter, relation between the minimum and maximum cell Ferret's diameter (respectively smaller and bigger rectangle side as circumscribed on any flat figure), cell elongation (the ratio between the difference in lengths of long and short ellipse axis with the best fit into a given object to the sum of these lengths). High number of cells for each varieties allowed obtaining statistical distribution of the mentioned structural parameters and gave information on the cell size and shape of each potato varieties.

The obtained data was then subjected to the Kołmogorow - Smirnow's normality test. The test showed that at the significance level of α=0.05, the D_{max} statistics is non-significant only in the case of cell perimeter. It means that all the remaining values: cell area, ratio of the minimum and maximum Feret's diameter ($Feret_{min/max}$) as well as cell elongation are not subjected to normal distribution. However, high number of objects (number of cells >>100), evaluation of likelihood of mean values can be carried out by means of confidence intervals.

Mechanical parameters

Mechanical tests on 'samples 1' for the three varieties were carried out simultaneously with the analysis of cell structure parameters. Samples were subjected to uniaxial compression at a constant rate of 5 mm min^{-1} in a testing apparatus Lloyd LRX. There were 30 repetitions for each varieties. Relation between stress and strain was measured .

Two mechanical parameters were determined: strength - as the maximum value of stress on the stress-strain curve and the modulus of elasticity - as the secant modulus in the range starting in the beginning of the stress-strain curve to the point where the sample reached half of its strength (Mohsenin, 1986).

RESULTS AND DISCUSSION

The results obtained for the three potato varieties: Danusia, Kuba and Triada, showed that each of the above varieties has a different structural composition (Fig. 2). It is possible to assess percentage cell contribution in individual size intervals, i.e., var. Kuba is characterised by the highest percentage contribution (45%,) of cells with the cell area of 1-2 x 10^4 μm^2 , whereas var. Danusia, contribution of cells with the same size is only about 37%. Similar comparisons can be made for the percentage contribution of the remaining structural parameters of the studied varieties (Fig. 2).

While comparing mean values of the structural parameters given in Table 1, it can be concluded that variety Danusia is built of cells with the biggest area and perimeter as compared to varieties Kuba and Triada. Whereas cell shape described as the ratio of Feret's diameters and elongation, is similar for all the studied varieties.

The three potato varieties with characteristic structural composition showed differentiated mechanical properties: strength and modulus of elasticity (Table 2). Varieties Kuba and Triada with similar but smaller cells showed higher strength, i.e.: 1.76 and 1.77 MPa, respectively, whereas variety Danusia with clearly bigger cells (mean cell area and cell perimeter in Table 1) are characterised by a lower

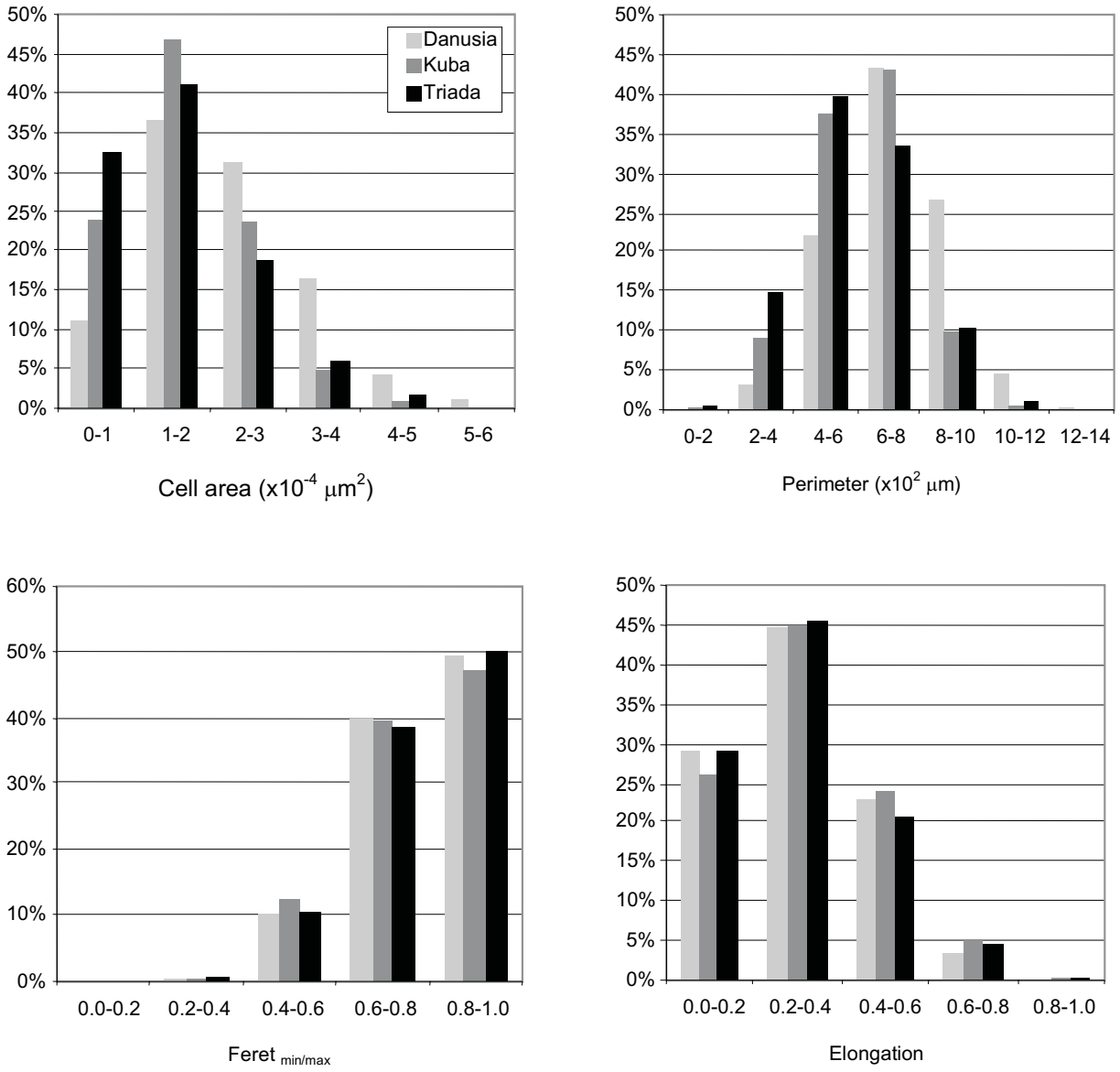

Fig. 2. Distribution of structural parameters (cell area, perimeter, Feret $_{min/max}$, elongation) of potato tuber tissue from the three studied varieties (Danusia, Kuba, Triada).

T a b l e 1. Mean values of structural parameters of potato tubers of the studied varieties with confidence intervals (α=0.05)

Variety	Structural parameter							
	Area (μm^2)	Confidence intervals	Perimeter (μm^2)	Confidence intervals	$Feret_{min/max}$	Confidence intervals	Elongation	Confidence intervals
Danusia	21946	379	715	6	2.83	0.05	0.316	0.006
Kuba	16191	224	610	4	2.93	0.04	0.330	0.005
Triada	15264	250	582	5	3.18	0.04	0.303	0.004

T a b l e 2. Mean values of mechanical parameters of potato tubers of the studied varieties with confidence intervals (α=0.05)

Variety	Mechanical parameter			
	Strength (MPa)	Confidence intervals	Modulus of elasticity (MPa)	Confidence intervals
Danusia	1.40	0.05	2.83	0.05
Kuba	1.76	0.06	2.93	0.07
Triada	1.77	0.07	3.18	0.06

strength of 1.4 MPa. Relations between modulus of elasticity of the studied varieties and the parameters describing cells size was also observed. Varieties with smaller cells have higher modulus of the elasticity. Cell shape parameters are similar for all the studied varieties and hence, no correlation between these values and the mechanical parameters was observed in the present experiment.

The observed relations between cell sizes and strength of the compressed sample are in agreement with results obtained by Haman *et al*. (1999), Konstankiewicz and Zdunek (2001) and with the model of crack development worked out by Haman and Konstankiewicz (2000). The model foresees that the tensile stress in the cell walls at a given turgor pressure and wall thickness, is higher for bigger cells. It means, that big cells crack first. It follows from the model, that plant tissue with bigger cells are more susceptible to breaking and in consequence, have lower strength. At present, it is difficult to interpret the influence of cell size on the modulus of elasticity of plant tissue due to the lack of an appropriate model and research on the above issue.

CONCLUSIONS

The present study on the influence of structure of potato tuber tissue on its mechanical properties allowed drawing the following conclusions:

1. Geometrical cell parameters of the potato tissue outer core are characteristic for each of the three studied varieties.

2. Varieties Triada and Kuba are built of cells that are similar in size, whereas the tissue of variety Danusia is characterised by significantly bigger cells and with longer perimeters.

3. Structural composition, and especially such parameters as cell area and cell perimeter of the studied potato tissue influence on mechanical properties, i.e., strength and modulus of elasticity. Varieties Kuba and Triada built of smaller cells have higher strength and modulus of elasticity than variety Danusia built of bigger cells.

4. Cell shapes (elongation and the ratio between the minimum and maximum Feret's diameter) is similar for all the studied varieties and do not correlate with their mechanical properties.

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