The influence of conductivity measurement on mechanical properties of potato tubers – Short communication

J. Blahovec, A. Yurov

Faculty of Engineering, Czech University of Life Sciences in Prague, Prague, Czech Republic

Abstract

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Deformation curves in uniaxial compression of raw potato tuber were analyzed at Nicola and Saturna varieties. In the first part of deformation (time 1 min), some part of specimens were loaded by electric field simulating simultaneous measurement of the specimen alternating-current conductivity (three levels of voltage 1, 5, and 10 V and three frequencies 1, 10, and 100 kHz). The obtained curves were analyzed by six parameters. In five of them no differences were approved statistically ($\alpha = 0.05$). Only in the case of modulus of elasticity some differences were observed; however, the differences cannot be simply explained by the influence of the electric field.

Keywords: potato; conductivity; deformation curve; voltage; frequency; deformation

Potato tuber permittivity during compression test was studied in a set of our previous papers (Sobotka et al. 2006, 2007; Blahovec, Sobotka 2007; Blahovec 2008). The effect of compression on both real and imaginary components of the complex permittivity was given with an attempt to separate the reversible and irreversible components of the effect (Blahovec 2008). The electric current of the measured circuit with the specimen as a part was low enough to omit the role of current heating of the tested specimen.

There are indications on fundamental role of electric field on structure and properties of cellular structures (e.g. Dejmek, Miywaki 2002; Fincan, Dejmek 2002). The main change in this process is the change in properties of the originally semi-permeable cellular cells that are followed by loss of the water content due to squeezing out of the cellular sap.

This is why we arranged a simple set of tests on potato tubers where we used external source of alternating-current (AC) of different parameters applied to the usual potato specimens during the first part of their deformation in an uniaxial compression test with the aim to detect potential differences in the main test parameters.

MATERIALS AND METHODS

The Nicola and Saturna varieties cultivated in the same standard conditions were tested in November 2008. The tubers were harvested in the end of September, stored in cold conditions and then transported to laboratory. The potatoes were then stored in a refrigerator for a few days at 7±1°C. One day prior to the test the tubers were washed in cold water and 20 defect-free tubers of mediate size (5 to 8 cm in diameter) were selected for the testing. All tubers of one variety were tested in the same week.

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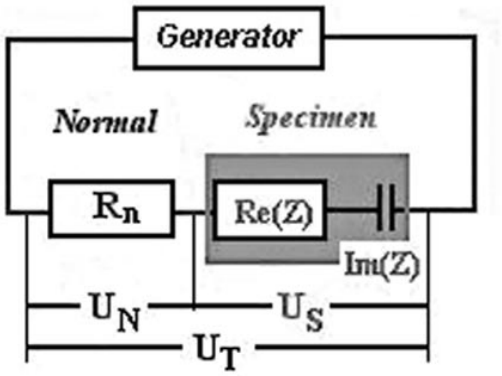

Fig. 1. Scheme of the electrical measurements during the first part of the deformation test

One specimen of cylindrical shape (approximately 15 mm in diameter and 20 mm in height) was cut from the central part of each tuber so that its axis was parallel to the stem-bud axis and the pith of the tuber was excluded preferably. A cork borer and special double knives were used for this purpose. After a more precise determination of the specimen's size, the specimen was deformed axially in compression in the loading/unloading regime with the deformation rate 0.0167 mm/s up to rupture. The mechanical tests were performed in the Instron® 4464 testing machine. The compression metallic isolated plates served at the same time as electrodes for AC into the specimen. The Agillent Generator 33220A was a source used in the same circuit as in the previous papers (Sobotka et al. 2006; Blahovec, Sobotka 2007; Blahovec 2008); the source parameters were voltage (U) and frequency (f) of sinusoidal signal. Into the circuit with the generator and the tested specimen, the stable Ohmic resistor (220 Ω) was connected serially. The scheme of the electrical measurement is given in Fig. 1, and the set of experiments is described in Table 1. The AC signal was switched out after 1 min of deformation. Every test was replicated ten times.

The corresponding strain (ε_i) and stress (σ_i) values were the primary data in mechanical tests and further calculations. The true (Hencky's) strain and stress were used systematically (Blahovec, Sobotka 2007). The obtained deformation curves had typical shape (Fig. 2) from which the following typical quantities were calculated: true strain at the strength limit (TSNS), true stress at the strength limit (TSSS), true strain at the yield limit (TSNY), true stress at the yield limit (TSSY), modulus of elasticity (E), and the slope of quasi-linear part above yield point gives modulus of flowing (E_f).

The obtained values were analyzed by ANOVA and Tukey's test using Origin version 7 software (OriginLab Corporation, Northampton, USA).

Table 1. The set of experiments – generator data

Variable (V)	1 kHz	10 kHz	100 kHz
10	H1	H10	H100
5	M1	M10	M100
1	L1	L10	L100
0		Z	

RESULTS AND DISCUSSION

Strength limit

The results obtained for strength limit are given in Table 2. The strain moves in very narrow limits 0.50–0.53, whereas the values of the mean strength limit move in wider limits 0.90–0.98 MPa. No remarkable influence of the electric loading in the first part of the test was obtained.

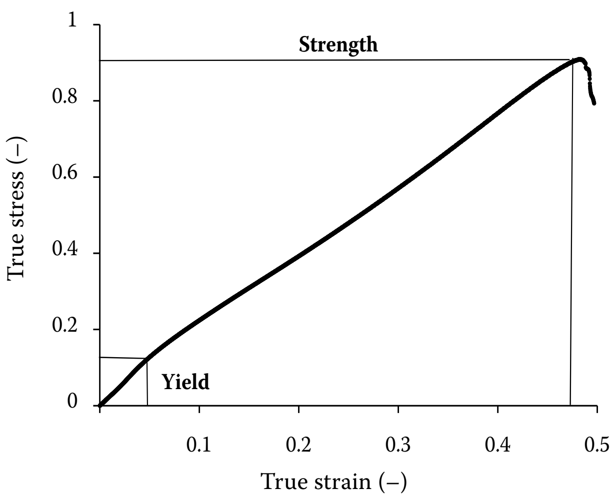

Fig. 2. Typical deformation curve obtained in the current tests. The specimen rupture is described by the strength parameters: True strain at the strength limit (TSNS) and true stress at the strength limit (TSSS). The curve is divided into two parts, the initial quasi-elastic part below the yield and the flow part above the yield. The yield is defined by two parameters: True strain at the yield limit (TSNY) and true stress at the yield limit (TSSY). The linear part below yield point gives by their slope modulus of elasticity (E), the slope of linear part above yield point gives modulus of flowing (E_w)

Table 2. The results obtained at strength limit: TSNS and TSSS (MPa)

Parameters	Nicola		Saturna	
	MV	SD	MV	SD
TSNS				
H1	0.526	0.035	0.517	0.026
H10	0.531	0.036	0.494	0.035
H100	0.504	0.032	0.530	0.062
M1	0.516	0.027	0.497	0.044
M10	0.504	0.032	0.522	0.032
M100	0.512	0.038	0.509	0.029
L1	0.516	0.041	0.492	0.042
L10	0.526	0.041	0.514	0.045
L100	0.530	0.038	0.504	0.045
Z	0.531	0.031	0.541	0.032
TSSS				
H1	0.926	0.061	0.930	0.081
H10	0.971	0.089	0.931	0.083
H100	0.965	0.088	0.907	0.080
M1	0.944	0.089	0.921	0.062
M10	0.905	0.071	0.947	0.061
M100	0.920	0.067	0.952	0.115
L1	0.978	0.079	0.929	0.069
L10	0.966	0.108	0.902	0.048
L100	0.953	0.074	0.930	0.066
Z	0.980	0.104	0.978	0.070

MV – mean value, SD – standard deviation, no-differences were obtained by Tukey's test ($\alpha = 0.05$)

Yield data

The results obtained for the yield limit are given in Table 3. The strain at the yield point was very variable; mean values in Table 3 for TSNY varied between 0.022 and 0.033 in many cases where the partial coefficients of variation overcame 100%. It is clear that in such conditions any differences between the separate sets of the data could not be determined. The obtained value of the yield stress was approximately the same in all separated tests. Its mean values move between 0.12 and 0.16 MPa. Coefficient of variation is close and below 20% in all cases. No remarkable influence of electric current in the specimens during the first part of the test was obtained.

Slope of tangent to deformation curve

Some differences were obtained for the slopes of deformation curves in the first "elastic" part where the tested specimens were also loaded by electric current. Traditionally, the slope of the initial linear part is termed as modulus of elasticity; its values obtained in our test are given in Table 4a. They varied in a wide range from 3.6 to 5.1 MPa, being rather higher at Nicola than at Saturna. The dependence on electric loading, if existed, was not too strong. At Nicola, some increasing values were observed for the voltage of 10 V in comparison to the other cases. No systematic influence of the AC frequencies was determined. The results for modu-

Table 3a. The results obtained at yield limit: TSNY and TSSY (MPa)

Parameters	Nicola		Saturna	
	MV	SD	MV	SD
TSNY				
H1	–	–	0.0188	0.0397
H10	0.0231	0.0218	0.0230	0.0290
H100	0.0194	0.0268	0.0232	0.0290
M1	0.0150	0.0244	0.0203	0.0263
M10	0.0141	0.0211	0.0246	0.0222
M100	0.0220	0.0260	0.0334	0.0291
L1	0.0112	0.0219	0.0156	0.0224
L10	0.0322	0.0267	0.0317	0.0441
L100	0.0158	0.0234	0.0206	0.0281
Z	0.0221	0.0222	0.0200	0.0281
TSSY				
H1	0.140	0.016	0.140	0.019
H10	0.141	0.024	0.130	0.025
H100	0.147	0.037	0.133	0.032
M1	0.145	0.022	0.130	0.026
M10	0.141	0.018	0.137	0.020
M100	0.147	0.024	0.145	0.029
L1	0.143	0.025	0.122	0.019
L10	0.156	0.025	0.135	0.032
L100	0.143	0.028	0.140	0.024
Z	0.156	0.017	0.140	0.030

MV – mean value, SD – standard deviation, no-differences were obtained by Tukey's test ($\alpha = 0.05$)

lus of flowing are plotted in Table 4b and Fig. 2. The resulting values were reproducible with coefficient of variation of few percent but the differences between experimental sets were also very low (Fig. 3) and so no differences were approved by Tukey's test.

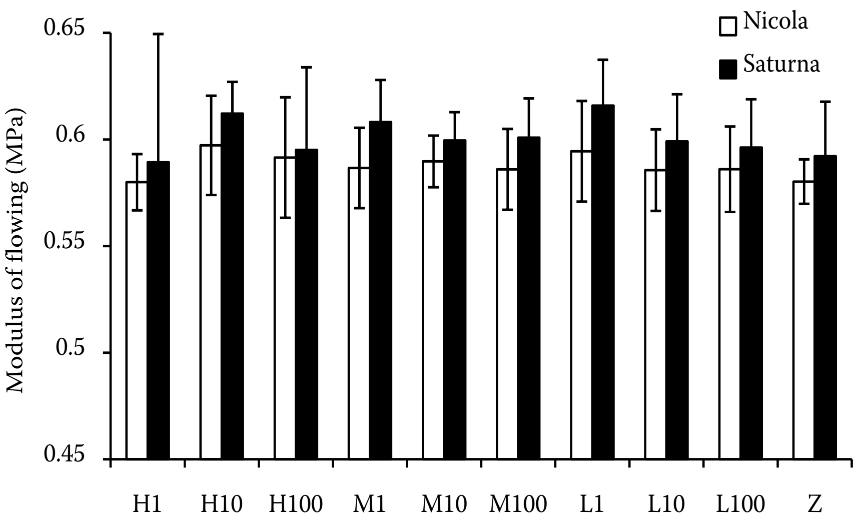

Fig. 3. Modulus of flowing E_f (MPa) obtained in the tests. The bars in the figure denote standard deviations. Symbols in the lower part of the figure denote the test variables (Table 1)

Table 4a. The results obtained for modulus of elasticity E (MPa)

Parameters	Nicola		Saturna	
	MV	SD	MV	SD
H1	4.71[d]	0.61	3.76[b]	0.82
H10	4.62[d]	0.83	4.12[c]	0.60
H100	4.62[d]	0.52	3.64[b]	0.48
M1	4.44[c]	0.41	3.79[b]	0.45
M10	4.05[c]	0.99	4.05[c]	0.54
M100	4.01[c]	0.87	4.09[c]	1.10
L1	5.10[e]	0.80	3.79[b]	0.58
L10	4.12[c]	0.68	3.45[a]	0.40
L100	4.42[c]	0.40	3.83[b]	0.37
Z	4.04[c]	0.91	4.12[c]	0.68

MV – mean value, SD – standard deviation, the differences denoted by superscripts a, b, c, d, e were determined using Tukey's test (α = 0.05)

Table 4b. The results obtained for modulus of flowing E_f (MPa)

Parameters	Nicola		Saturna	
	MV	SD	MV	SD
H1	0.580	0.013	0.589	0.060
H10	0.597	0.023	0.612	0.015
H100	0.592	0.028	0.595	0.039
M1	0.587	0.019	0.608	0.020
M10	0.590	0.012	0.600	0.013
M100	0.586	0.019	0.601	0.018
L1	0.594	0.024	0.616	0.022
L10	0.586	0.019	0.599	0.022
L100	0.586	0.020	0.596	0.023
Z	0.580	0.010	0.592	0.026

MV – mean value, SD – standard deviation, no-differences were obtained by Tukey's test (α = 0.05)

CONCLUSIONS

The true stress-true strain deformation curves of raw potato tubers (Nicola and Saturna varieties) are very similar one to another even if the electric conductivity is measured during the first part of the test at frequencies 1–100 kHz and maximum intensity of electric field well below 1 kV/m ($2^{1/2} \times 10$ V/0.02 m ~ 707 V/m). From six basic parameters of the deformation curve some differences were approved only for modulus of elasticity, even if no system of the observed differences was found. For the other analyzed parameters no differences were approved statistically.

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References

Blahovec J., 2008. Dielectric properties of deformed early potatoes. Research in Agricultural Engineering, *54*: 113–122.

Blahovec J., Sobotka J., 2007. Potato tuber permittivity during deformation in compression. Research in Agricultural Engineering, *53*: 79–84.

Dejmek P., Miywaki O., 2002. Relationship between the rheological properties of potato tuber tissue after various forms of processing. Bioscience, Biotechnology, and Biochemistry, *66*: 1218–1223.

Fincan M., Dejmek P., 2002. In situ visualization of the effect of a pulsed electric field on plant tissue. Journal of food engineering, *55*: 223–230.

Sobotka J., Krejčí J., Blahovec J., 2006. Electric permittivity of potato during compression test. In: Blahovec J. (ed.), The Hidden and the Masked in Agricultural and Biological Engineering. Prague, Czech University of Agriculture Prague: 89–94.

Sobotka J., Krejčí J., Blahovec J., 2007. Equipment for the determination of dielectric properties of vegetable tissue during its mechanical loading. Research in Agricultural Engineering, *53*: 143–148.

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Corresponding author:

Prof. RNDr. Ing. Jiří Blahovec, DrSc., Czech University of Life Science, Faculty of Engineering,
Kamýcká 129, 165 21 Prague 6-Suchdol, Czech Republic
phone: + 420 224 384 281, fax: + 420 234 381 828, e-mail: blahovec@tf.czu.cz