ELECTRICAL IMPEDANCE SPECTROSCOPY AS A NONDESTRUCTIVE METHOD IN FRUIT QUALITY ASSESSMENT

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Abstract

Electrical impedance spectrum of whole intact and artificially bruised apples with and without skin was measured in frequency range from 10 Hz-up to 1 MHz. The measured spectra were approached with electrical model circuit consist of serial resultant of distributed elements. Parameters - characterizing the apple flesh impedance - evaluated for apples with skin were in good concordance of apple flesh parameters obtained on apple without skin. The resistance of extra cellular part of apple flesh on apples with skin was higher in comparison with intercellular part resistance on peeled apples. The magnitude of extra cellular part resistance of apple flesh drastically decreased, if the cell membranes were broken. Apple skin resistance also decreased as the bruises increased. The relaxation time both in extra cellular part and in apple skin decreased, as the injuries became accentuated. At the same time the intracellular relaxation time slightly decreased. The exponent parameters were not sensitive to injuries. The impedance spectrum measured on whole apple with skin contains the impedance spectrum of apple flesh under the skin, and the impedance parameters of apple flesh can be used for quality assessment of apple flesh under the skin.

Key words: electrical impedance spectrum, non-destructive method, quality assessment, fruit, vegetables

Introduction

The electrical impedance spectrum - in low frequency range - of biological tissues depends on the state of cellular structure (1), therefore the parameters evaluated from measured spectrum can be used for quality assessment of fruits and vegetables (2). In majority of works the impedance spectrum is measured with pin electrodes (2,4,5) and so the intact structure is injured. There are few measurements performed with non-destructive electrodes (3).

Recently there is a great demand on non-destructive investigating methods. In this work the impedance spectrum measured on the surface of whole apple with skin was approached with impedance of model circuit consisting of serial resultant of apple skin impedance and apple flesh impedance. The model parameters, characterizing the apple skin and flesh were evaluated. The parameters of apple flesh were compared with impedance parameters obtained from approaching the impedance spectrum measured on apple flesh without skin for both intact and injured apples.

Materials and Methods

Idared apples were purchased on the local market. Impedance spectra were determined on both intact and bruised whole apples. The bruises under the apple skin were artificially established. Apple flesh named as "pressed" was caused by press of apple skin with force less than bioyield point. Under such low force only the shape of cells changes and the cell membrane remains unbroken. "Pulpy" apple flesh was caused by pressing force much higher than bioyield point. In this case the membrane is broken. Impedance of ten apples from each group – intact, pressed and pulpy - was determined. The measurements were performed on apple with skin and without skin, on apple flesh.

The magnitude and phase angle of impedance spectra were measured with an HP 4284A LCR precision meter in a frequency range from 30 Hz up to 1 MHz. The measuring voltage was 1 V. The measured spectra were open and short corrected, to eliminate the stray capacitance and inductance. Fiab Spa Ag/AgCl ECG electrodes with 10 mm diameter were used. A special conducting gel was used for the good electrical contact between the electrode and the apple skin, or apple flesh.

The corrected impedance spectra of the whole apple with skin were approached with a model consisting of serial resultant of three distributed elements and an ohmic resistance

$$R+\frac{R_1}{1+(i\tau_1\omega)^{\psi_1}}+\frac{R_2}{1+(i\tau_2\omega)^{\psi_2}}+\frac{R_3}{1+(i\tau_3\omega)^{\psi_3}}, \quad (1)$$

where R, R_1, R_2 and R_3 are resistance, τ_1, τ_2 and τ_3 are relaxation times, ψ_1, ψ_2 and ψ_3 exponents characterize the distribution of relaxation times, $\omega = 2\pi f$ and f is the measuring frequency. A model consisting of only two distributed elements and one resistance was fit to spectra of apple flesh. The approaching procedure was performed with complex non-linear least squares (CNLS) method by MathLab program.

Variance analysis, a Dunnett T3 test was performed ($P < 0.05$) on impedance parameters (SPSS 12.0 for Windows, SPSS Inc., Chicago, IL, USA).

This model can be considered as an explanatory model. The first distributed element can characterize the impedance of apple skin. The second and the third element can give impedance parameters of extra cellular and intracellular part of apple flesh tissue, respectively.

Results and Discussion

The measured and corrected spectra of apple with skin (Fig.1.) were approached with serial resultant of three distributed elements and one ohmic resistance. A typical approach can be seen on the Fig. 2.

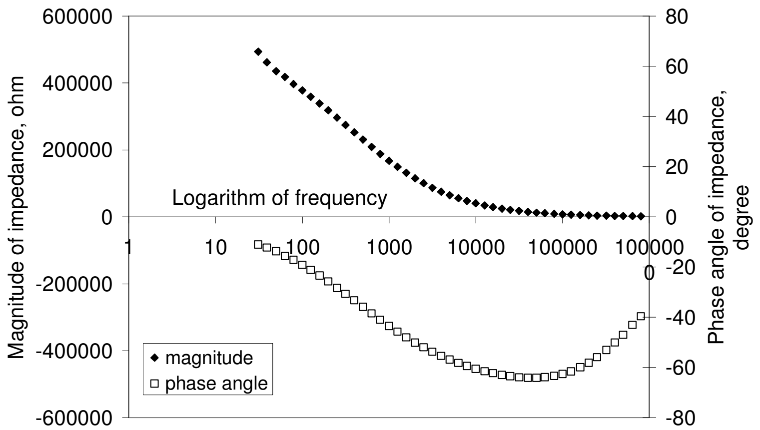


Fig. 1. Typical measured impedance magnitude and phase angle on apple with skin

Generally the approach at low and high frequency not very good, because of in biological tissue there are other polarization effects - at low frequency the ion movements, at high frequency the polarization of bound water (1).

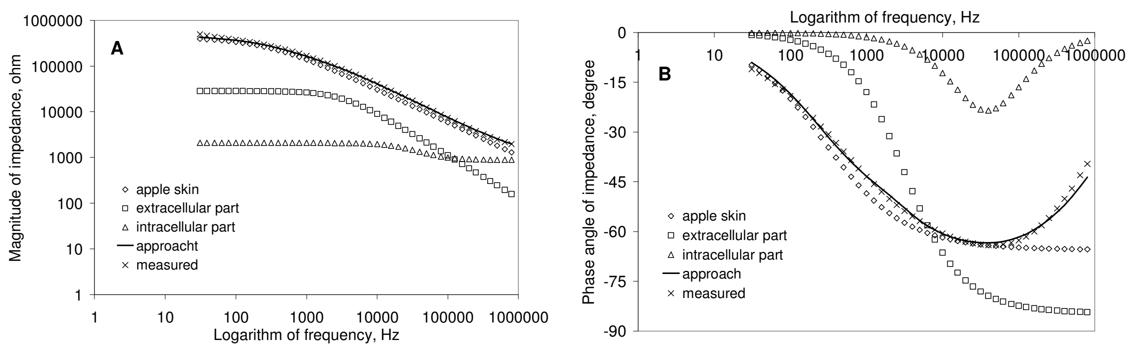


Fig. 2. Typical approach of magnitude (A) and phase angle (B) of measured impedance

Impedance spectra measured on peeled apples were approached with model consisting of two distributed element in serial connection with each other and with an omic resistance.
The value of extra cellular resistance (R_2) parameters practically is the same for apple with skin and for apple flesh for the all three groups of apple tissue (Fig.3.A). Force below bioyield does not cause resistance decrease. The standard deviation is higher for both resistances and relaxation times obtained from approach on apple with skin in comparison

with standard deviation of these parameters from spectrum of peeled apples (Fig, 3. A and B).

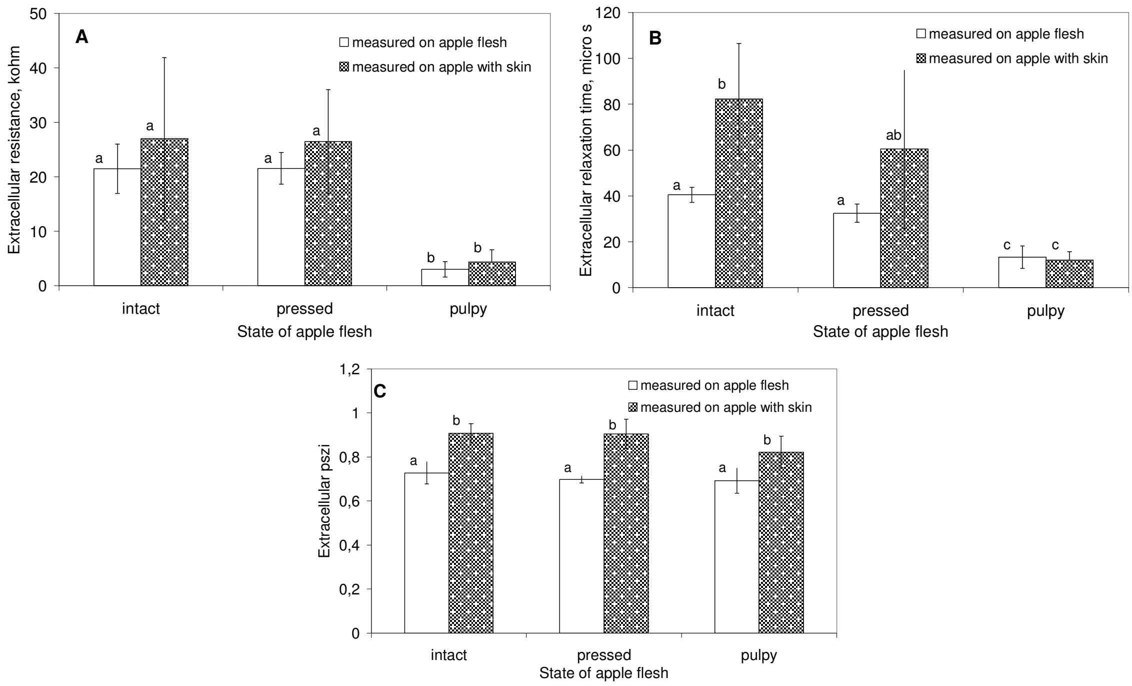
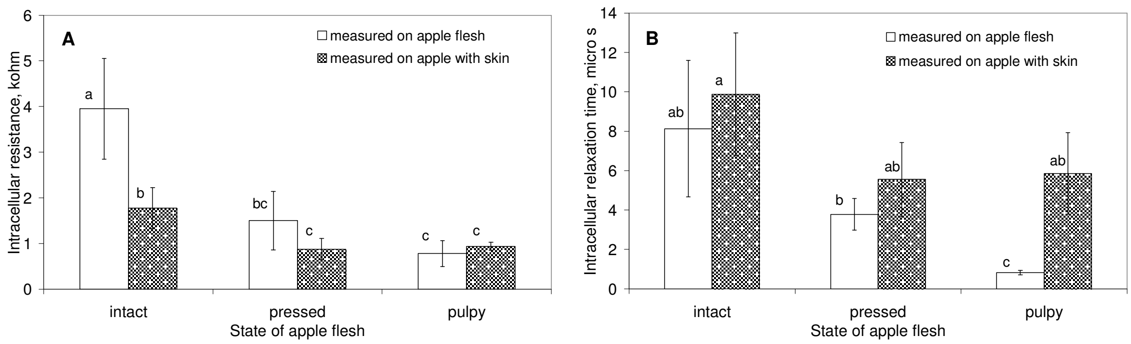


Fig. 3. Impedance parameters (average with standard deviation) of extra cellular part of apple flesh measured on apple with and without skin. A: resistance, B: relaxation time, C: exponent characterizing the distribution of relaxation times. The same letter in a picture means there is no significant difference ($P < 0.05$) in the values of parameter



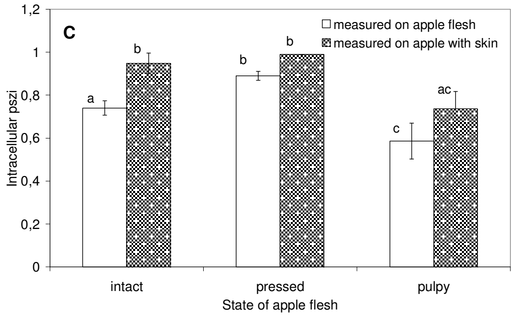


Fig. 4. Impedance parameters (average with standard deviation) of intracellular part of apple flesh measured on apple with and without skin. A: resistance, B: relaxation time, C: exponent characterizing the distribution of relaxation times. The same letter in a picture means there is no significant difference (P < 0.05) in the values of parameter

Impedance parameters of intracellular part of apple flesh in some case – resistance in intact apple flesh (Fig,4. A), relaxation time in pulpy apple flash (Fig. 4. B) – there are relative large differences in values obtained in apple with skin and in peeled apple. Therefore these parameters can not be used for characterizing the apple flesh state under the skin.

Table 1. R parameter and impedance parameters of apple skin . The same letter in a column means there is no significant difference (P < 0.05) in the values of parameter

	Ro, kohm	Ro, kohm		R1, kohm	tau1, ms	pszi1
State of apple flesh	measured on apple flesh	measured on apple with skin		measured oh apple with skin		
intact	2,26±0,54a	1,05±0,26b		350±2204a	6,15±5,93a	0,778±0,033a
pressed	1,79±0,15a	0,79±0,90b		700±184b	0,504±0,23b	0,747±0,017a
pulpy	0,7±0,24b	0,61±0,07b		36,5±35,14c	0,025±0,026c	0,751±0,060a

The R parameter shows decreasing tendency as the structure injury increases (Table 1.), but the difference between values for apple with skin and for apple flesh is relative high.
The resistance (R_1) and the relaxation time (τ_1) for apple skin drastically decrease as the damage of membrane structure is intensifying (Table 1).
The resistance of extra cellular part of apple flesh on apples with skin was higher in comparison with intercellular part resistance on peeled apples. This difference can be explained by the mixing of inter and intra cellular part on the peeled surface. The magnitude of extra cellular part resistance of apple flesh drastically decreased, if the cell membranes were broken, in apple pulpy. The intracellular part resistance was not so sensitive on the apple flesh bruises, as the intercellular part. Both resistance, R, and apple skin resistance also decreased as the bruises increased.
The relaxation time both in extra cellular part and in apple skin decreased, as the injuries became accentuated. At the same time the intracellular relaxation time slightly decreased.

The exponent parameters of apple flesh had higher value in apples with skin, as in peeled apples both in extra and intra cellular part. These parameters were not sensitive to injuries.

Conclusions

The impedance spectrum measured on whole apple with skin contains the impedance spectrum of apple flesh under the skin, too. There are some impedance parameters of apple flesh, which can be used for quality assessment of apple flesh under the skin. The resistance and the relaxation times of extra cellular part are seemed to follow the changes in cell structure.

References

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