



THERMAL ANALYSIS OF ROOT VEGETABLE AT 30 – 90 °C

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Abstract

Roots of carrot, parsley and black radish were studied by DMA in temperature range 30 – 90 °C using vibrations with frequency 1 Hz and temperature increase 1 °C/minute. From directed measured quantities the storage modulus and the loss modulus were determined and the relative temperature slopes (SMR and LMR) were calculated. These new quantities have a characteristic minimum at temperatures T_m at 50 – 70 °C. It was shown that with increasing T_m the observed minima of SMR and LRM are deeper. The observed behavior is discussed in relation with thermal destruction of the cell membranes; initially due to cell pore proteins denaturation and lately by direct destruction of the cell wall membrane. Deeper knowledge of the thermal stimulated processes in the cell walls of vegetable is important for their optimal processing as food components.

Key words: DMA, modulus of elasticity, cell membrane, destruction, cooking.

INTRODUCTION

Thermal processing of fruits and vegetables is a frequent operation in every kitchen. In last years (E.G. IMAIZUMI ET AL., 2015; FUENTES ET AL., 2014) it is more and more clear that quality of the product of thermal processing in this case sensitively depends on details of the whole process. Although the role of temperature as an important external parameter for living organisms is generally known (GARRET AND GRISHAM, 2010), there is still a lack of information on the details of the parallel processes taking place in living cells and tissues as well as in some foods during their heating. The group of methods applied in this area for indirect study of the processes includes the methods of thermal analysis (PRICE, 2002). The modulus of elasticity of a tested specimen is the main recorded parameter in a DMA test during the specimen heating (GEORGET ET AL., 2002; PRICE, 2002). The DMA test makes possible the measurement of two components of the complex modulus: the real part (storage modulus, SM) expressing the elastic part of the material toughness, and the imaginary part (loss modulus, LM) describing the inelastic (fluid) part of the toughness. The modulus of elasticity of cellular walls decreases with increasing temperature in the same way as the modulus of elasticity of other substances (WARD, 1983). This decrease, as well as the changes in the intracellular pressure during the specimen heating, can be displayed in DMA's modulus-temperature plots.

Equilibrium between the tissue symplast and its apoplast plays an important role in the temperature controlled tissue properties (PERSONIUS AND SHARP, 1938; SAKURAI, 2002): changes in this equilibrium can

be well detected also by electric means (IMAIZUMI ET AL., 2015; FUENTES ET AL., 2014).

In previous papers (BLAHOVEC AND LAHODOVÁ, 2011, 2012; BLAHOVEC ET AL., 2012) we used DMA for the detection of starch swelling in cells of potato parenchyma under conditions of high humidity. The observed characteristic peaks at temperatures above 70 °C, i.e. close to the temperature of starch gelatinization in potato tubers (KARLSSON AND ELIASSON, 2003 A,B) were explained by the cell starch swelling pressure (BLAHOVEC AND LAHODOVÁ, 2011). Similar role can be played also by the cellular turgor pressure as an important source of the tissue toughness (NILSSON ET AL., 1958). The turgor pressure sensitively depends on the temperature stimulated changes in the cellular plasmodesma (e.g. the changes in the pore protein conformation – folding - caused e.g. by the protein denaturation - MAULE, 2008; MINETTI AND REMETA, 2006; SEIDI ET AL., 2009; TSONG AND SU, 1999). The pore proteins have very complicated structures; thus, for the structure of plasmodesma, MAULE (2008) gave more than 20 components and different proteins including of cytoskeletal components, such as actin, and dynamic motor proteins such as myosin. The temperature stimulated folding in the conformed components can cause deep changes in pore function (KUBELKA ET AL., 2004) and may be also a source of the plasmodesma stability (DE WEER, 2000). The changes in the plant tissue rigidity during heating at temperatures 40-80 °C, i.e. at protein denaturation temperatures, were observed in previous DMA experiments (for carrot see BLAHOVEC AND LAHODOVÁ, 2012A; XU AND LI, 2014).



Trying to detect the basic changes in the vegetable cell membrane during its heating, we applied standard DMA to three vegetable products. We supposed under the standard hypothesis that the heating process causes the same and/or similar changes in the plasmodesma.

MATERIALS AND METHODS

Fresh roots of carrot (*Daucus carota*, subsp. *Sativa*, diameter about 4 cm and length about 15 cm), parsley (diameter also about 4 cm), and black radish (diameter about 10 cm) were bought from the local market and stored in cold and wet conditions (4 °C, 85% relative humidity). After a short storage (less than 2 weeks), the roots were washed in cold water. The selected defect-free roots of medium size were then left at room temperature for testing the next day.

Rectangular specimens measuring 8 (width) × 3 (thickness) × 22 (length) mm with the long axis parallel to the root axis were cut from the myzoderma (outer part of the tested roots) using special cutting jigs. From one root, four specimens were prepared. In case of carrot and black radish the specimens of the same dimensions were also prepared from the central part of the roots. In these cases we distinguished outer and central parts.

The DMA experiment was performed with a special DMA instrument, constructed by RMI company (Pardubice, Czech Republic), model DX04TC. Each spec-

The main aim of the experiments is to detect the possible differences in the resulting changes caused by the standard heating process in the DMA temperature scan.

imen was mechanically fixed in two points so that the longitudinal axis was perpendicular to the fixing jaws. The free length of the specimen between the jaws was 10.8 mm. The height of the fixed specimen was approx. 3 mm. One of the jaws was fixed, while the other moved up and down with a constant amplitude = 1 mm at a frequency = 1 Hz. The force connected with the oscillation was recorded, being the basis for the complex modulus determination (storage - SM and loss - LM). The moduli values (originally in Pa) are sensitive to the form of the tested specimen. To prevent this source of variation we calculated the resulting SM and LM values as a ratio of the corresponding value obtained for SM at 30 °C. This method is suitable for the determination of peak positions and the slope analysis. Every experiment started at a temperature of 30 °C and 90% air humidity in the test chamber. The humidity was kept constant during the whole experiment, while the temperature increased up to 90 °C with constant rate 1 °C/minute. Every test was repeated ten times using fresh specimens.

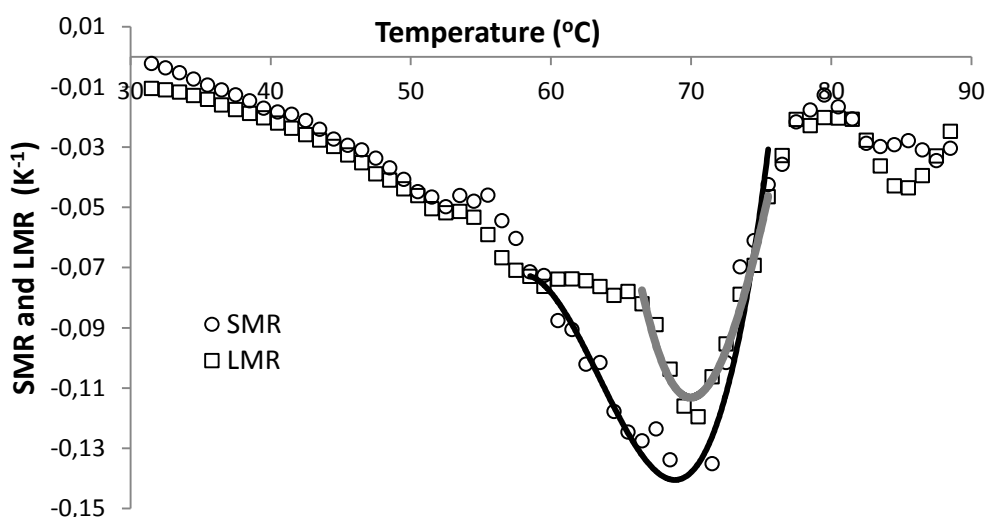


Fig. 1. – Typical temperature plots of SMR and LMR. The data were obtained for central parts of carrot. Approximation by cubic polynomials (Eq. (2)) is given by thick lines (black for SRM and grey for LMR)

The experimental results were analyzed using the standard laboratory software OriginPro Ver. 7 (Origin Lab, Northampton, MA, USA). The analysis was

focused on the temperature slopes of SM and LM that are expressed in logarithmic scale. The resulting parameters denoted as SMR and LMR defined by the



following formula (BLAHOVEC AND LAHODOVA, 2013):

$$SMR = \frac{1}{SM} \frac{dSM}{dT} = \frac{d \ln(SM)}{dT} \quad (1a)$$

$$LMR = \frac{1}{LM} \frac{dLM}{dT} = \frac{d \ln(LM)}{dT} \quad (1b)$$

where T is temperature. Both SMR and LMR have the same dimension: K^{-1} . The data were analysed using

the software Origin® with smoothing the data initially by averaging every 5 neighbouring points, followed by differentiating the smoothed data. The data obtained from the analysis of the slopes of the individual plots were then unified and classified into classes of 1 °C wide. The basic statistical analysis of the individual classes was then done using a special FORTRAN program made for this purpose.

RESULTS AND DISCUSSION

Examples of the measured thermal scans are given in Fig. 1, where are plotted SMR and LMR (see Eq. (1 a,b)) for the central part of carrot. This figure contains typical minima in range 50-70 °C. The experimental scans were approximated close to their minima by cubic polynomials (see Fig. 1):

$$y = a + bT + cT^2 + eT^3 \quad (2)$$

and positions of the minima T_m were then found by solving the quadratic equation:

$$\frac{dy}{dT} = 3eT_m^2 + 2cT_m + b = 0 \quad (2a)$$

Tab. 1. – Results obtained by analysis of SMR minima from Fig. 1. Eqs. (1) and (1a) are used

	Carrot O	Carrot C	Parsley	Radish O	Radish C
$e/0.00001$	8.18	10.83	-22.32	-6.05	-7.47
c	-0.0152	-0.0206	0.0433	0.0108	0.0131
b	0.936	1.299	-2.794	-0.640	-0.759
a	-19.04	-27.18	59.75	12.50	14.54
R^2	0.913	0.893	0.839	0.862	0.915
T_m	68.6	68.8	60.9	55.0	54.4
SMR_m	-0.149	-0.139	-0.119	-0.076	-0.092

Symbol O and C mean the outer part of root and the central part of root, respectively

Tab. 2. – Results obtained by analysis of LMR minima from Fig. 1. Eqs. (1) and (1a) are used

	Carrot O	Carrot C	Parsley	Radish O	Radish C
$e/0.00001$	-0.36032	-8.7658	-5.4488	-8.0803	-3.6397
c	0.0014	0.0211	0.0112	0.0141	0.0066
b	-0.140	-1.661	-0.760	-0.812	-0.396
a	3.97	42.96	17.05	15.54	7.80
R^2	0.930	0.961	0.843	0.902	0.913
T_m	65.4	70.0	63.2	54.7	55.4
LMR_m	-0.114	-0.115	-0.094	-0.069	-0.079

Symbol O and C mean the outer part of root and the central part of root, respectively

Analysis of all minima was performed and resulting values are concentrated in Tab. 1 and 2. These tables show that the obtained values for T_m differ for different analyzed roots and they are also different for SRM and LRM. It means that the processes detected in the heated roots are not spontaneous and well defined by temperature only. Its character is rather kinetic, i.e. they depend not only on temperature but also on time;

temperature scans depend on rate of heating as it was observed previously (BLAHOVEC AND LAHODOVA, 2012A). Both SMR_m and LMR_m in Tab. 1 and 2 decrease with increasing T_m . More exactly it is described in Fig. 2 where the relations between both characteristic quantities SMR_m and LRM_m and the temperatures in the observed minima were approximated by lines.



The corresponding linear equations have a common point at $T_{mm} = 44.26\text{ }^{\circ}\text{C}$ with $\text{SMR}_{mm} = \text{LRM}_{mm} = -0.0423\text{ K}^{-1}$. It seems that at this temperature begins the thermal range in which the vegetable cells are opened by the thermally activated denaturation of cell pore proteins (BLAHOVEC AND LAHODOVA, 2012A; IMAIZUMI ET AL., 2015). This

process is very complicated and can be influenced either by the type of plant, the conditions of cultivation, the variety, the conditions of storing, and of cause the details of heating. BLAHOVEC AND LAHODOVA (2012A) observed that for carrot the quicker heating leads to higher T_m values, sometimes higher than $70\text{ }^{\circ}\text{C}$.

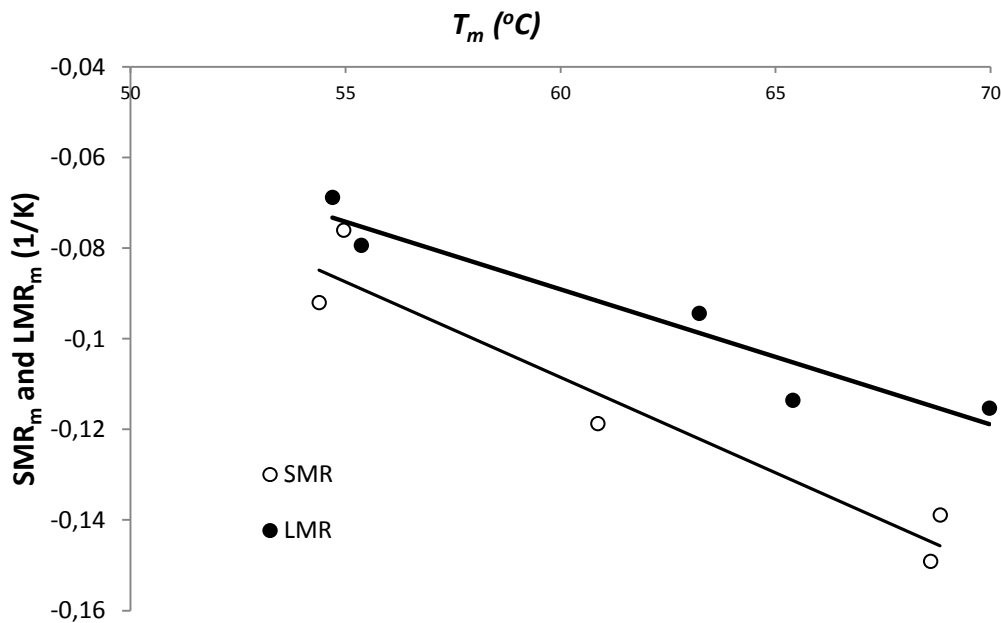


Fig. 2. – Relations between positions of minima (T_m) and their values (SMR_m and LMR_m)

Data were taken from Tab. 1 and 2 and were approximated by linear relations:

$$\text{SMR}_m = 0.14404 - 0.00421T_m; R^2 = 0.924$$

$$\text{LMR}_m = 0.09004 - 0.00299T_m; R^2 = 0.918$$

For the common point at T_{mm} , the relative differential activation energy (RDAE – see BLAHOVEC AND LAHODOVA, 2012A IN EQ. (2A) AND (2B)) was determined as 686.54 K . It has to be lowest value of this quantity for our vegetables – this value could be reached at very slow heating. New mechanism of

direct destruction of cellular membrane starts to operate at temperatures close to or above $70\text{ }^{\circ}\text{C}$ (BLAHOVEC ET AL., 2015; BLAHOVEC AND KOUŘÍM, 2016). The effect of the new mechanism is more effective when activity of the previously mentioned mechanism controlled by pores was lower.

CONCLUSIONS

Cell membrane is destructed during heating of root vegetable. The process starts at temperatures just above $40\text{ }^{\circ}\text{C}$. Its mechanism consists probably in denaturation of proteins in the cell wall pores. Role of this mechanism increases with decreasing heating rate

and it is also different in different roots. At temperatures close and/or above $70\text{ }^{\circ}\text{C}$ the role of pore is finished and it is replaced by thermally induced destruction of the whole cell membrane.



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