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Pulsed electric stimulated changes in potatoes during their cooking: DMA and DETA analysis

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A B S T R A C T

The internal cortex of potato (two varieties: Dali and Agria) was tested using dynamic mechanical analysis (DMA) combined with dielectric thermal analysis (DETA), in air of 90% humidity in temperature scans between 30 and 90 °C. Temperature plots of storage (*SM* i.e. elastic) and loss (*LM* i.e. inelastic) moduli were obtained. DETA, based on alternated current of frequency 20 kHz, continually determined both components of impedance. The PEF (pulse electric field) was applied prior to the DMA/DETA test; the experiments were arranged into four sets: b (no PEF), c (one 10 ms long pulse of alternated field 500 V/cm), d (two same pulses with a 0.1 s interval between them), e (the same pulses with a 1 s interval). The impedance was recalculated giving parameters of a single model represented by parallel connection of a resistor R_e and a capacitor with capacitance ωC. The temperature range was divided into three stages: A (30–60 °C), B (60–80 °C), and C (80–90 °C). For set b and stage A parameter R_e decreased, whereas capacitance was nearly constant. Both parameters were constant in stage C. In part B, between 70 and 80 °C, R_e sharply decreased and the capacitance showed a sharp peak, both indicating either collapse of the cellular membranes or starch gelatinization. Application of PEF led to reduction of the peak but the process was more effective when application of PEF was repeated (sets d and e) and mainly if longer time interval between the pulses was used (e). PEF causes disintegration of cellular membranes and water release from vacuoles so that free vacuole's water makes possible that starch gelatinization appears at lower temperatures. The role of PEF as a disintegration source was tested and it was found that its efficiency is strongly enlarged when it is combined with heating.

1. Introduction

The main part of a cooking process is used to bring the product texture to such a state that is savoury to a consumer. Recently, the combination of thermal processing with electric pulses has been applied for this purpose. It is known that the application of an external pulsing electric field (Tsong and Su, 1999; De Vito et al., 2008; Vorobiev and Lebovka, 2010) can damage the integrity of cellular membranes. De Vito et al. (2008) evaluated the state of cellular membranes after combined thermal and pulse electric processing by a special parameter Z (Lebovka et al., 2002), termed disintegration parameter. This parameter is given by the actual state of the material's electric conductivity σ. Z varies between 0, for material in the initial untreated state with conductivity σ_u and 1 for materials with totally disintegrated cellular membranes with conductivity σ_d:

$$Z = \frac{\sigma - \sigma_u}{\sigma_d - \sigma_u} \quad (1)$$

In practical cases, σ_d was estimated by direct measurement of conductivity after long and high electric pulse processing of the tested material: De Vito et al. (2008) used 0.1 s long pulses with 1 kV/cm intensity for apples. The disintegration effect of such a process is determined by parameters of the pulse procedure, by temperature of the thermal processing and also by the time schedule of the whole process.

The important role of temperature as an external parameter for living matter is generally known. Although the effects of temperature variation are more or less known (Garret and Grisham, 2010), there is still lack of information about details of the parallel processes taking place in living cells and tissues during heating. The behaviour of cellular complexes has to be studied by indirect methods, in which the characteristic states are indicated. For such purposes the methods of thermal analysis (Haines, 2002) are used, provided that specimens' drying due to increasing temperature is prevented (Blahovec et al., 2012; Blahovec and Lahodová, 2012b). Previous success of DMA in studies of thermally controlled changes in potato tuber (Blahovec and Lahodová, 2012b) was an inspiration for applying of the DMA to carrot

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(Blahovec and Lahodová, 2012a; Xu and Li, 2014).

The combination of electric pulses and simple heating procedures could form a new way of processing in the culinary area and cooking technology. Any reduction of heating in food processing is a source of energy conservation and reduction of food components losses that are caused primarily due to the application of higher temperatures. This is important mainly in fruits and vegetables where heating is followed by losses of vitamins and other unstable important nutrients.

Potato is a good model material for vegetables with higher starch content. It can serve as a testing medium in this kind of vegetables for detecting changes caused by different modifications of food and/or cooking technologies (Imaizumi et al., 2015) and also by the application of electric fields. Potatoes belong to the kind of vegetables for which the pulse electric fields are of high interest (Vorobiev and Lebovka, 2010).

In this paper, we use thermal analysis (DMA – Dynamic Mechanical Analysis and DETA - Dielectric Thermal Analysis - Haines, 2002) for studying the changes caused in potatoes by electric pulses. The aim of this paper is to find the temperature range suitable for the combination of pulse-electric methods with thermal cooking methods applied to potatoes.

2. Materials and methods

2.1. Test material

The potatoes used (varieties Dali and Agria) were cultivated in the Potato Research Institute in Havlíčkův Brod (Czech Republic) using standard farm technology. The varieties differ in their cooking properties: whereas the variety Dali is of type BA (more waxy), the variety Agria is of type B (more floury). The harvested tubers (September 2017), were selected and the damage-free tubers (diameter 6–8 cm) were stored at least for two months at standard conditions (6 °C, 85% relative humidity). After their transport to the laboratory the tubers were stored shortly at comparable conditions (6 °C, 85% relative humidity) in a refrigerator. The tubers prepared for experiments were kept at room temperature for testing the next day.

2.2. Specimens and basic DMA/DETA test

Rectangular specimens (5.1 - width × 3.6 - thickness × 35 - length) mm with their long axis parallel to the potato grow direction (from bud to stem ends) were cut from the internal cortex (parenchyma) part by a knife using special cutting jigs keeping constant the dimensions and the rectangular shape of the specimens (Blahovec and Kouřím, 2016). Participation of other kinds of the tuber tissues in the specimens was carefully excluded. From one tuber, about four specimens were prepared. The following procedures were performed with every specimen: measurement of its impedance after its fixation to the DMA tester (see further) at temperature 20 °C (the initial specimen impedance). This measurement gave the initial values of the specimen impedance: real component R_0 and imaginary component X_0. The DMA instrument was arranged so that the electric properties of the tested specimen could be continuously measured as a real conductor described by the complex impedance: An RLC meter (Hameg 8118 with voltage appr. 1 V, frequency 20 kHz and 3 sampling per minute) was used for this purpose. The specimen was carefully 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 appr. 3.8 mm.

One set of the specimens (5 repetitions) was used for a standard DMA/DETA test (Blahovec and Kouřím, 2016); this set was denoted as the basic, shortly b. One of the jaws was fixed and the other was moving up and down with constant amplitude of 1 mm and a frequency of 1 Hz in the dynamic cantilever test. The force necessary for the oscillation was recorded, being the basis for the complex modulus determination. Every experiment started at 30 °C; the relative values of the complex moduli were calculated by dividing the real values by the initial value of the real component (denoted as the storage modulus – *SM*). The role of the imaginary part (*LS* – loss modulus – see Blahovec et al., 2012) in DMA test is described by the ratio *LM*/*SM*. The air humidity in the test chamber (90%) was kept constant during the whole experiment. The control of the air humidity in the test chamber was based on direct humidity measurement by a special hygrometer and water vapour ejection into the chamber. The temperature scan proceeded up to 90 °C with a rate of 1 K/min.

The results of the DETA test were plotted on temperature plots of the impedance components: real R_r and imaginary X_r. Also, in this case, we preferred to present the results of our experiments as relative results: $R = R_r/R_0$, and $X = X_r/R_0$, where R_0 is the initial value of the real component of the specimen at 20 °C. This recalculation helps to reduce potential dimensional and surface variations in the prepared specimens.

2.3. PEF application

The specimens included in the sets for further testing (5 repetitions in every case) were removed from the DMA instrument after measurement of the initial impedance (see above) and loaded in the electric pulse (-s) equipment between two steel electrodes 2 cm in diameter which were placed in the central parts of the specimen perpendicularly to their 3.6 × 35 mm^2 sides.

Pulse loadings were performed using a special equipment (Blahovec et al., 2015): the basic AC sinusoidal signal with a frequency of 20 kHz was modulated into a nearly rectangular form of 10 ms length and height corresponding to the field intensity of 500 V/cm into the tested specimen. Preliminary tests showed that the pulse leads to a rather low decrease of the specimen's impedance. This is why we tried to use two consequent pulses, but we found that the pulses' effects depend on the length of the interval between them. This effect is described in Fig. 1 in which both impedance components decreases with increasing the interval between the pulses and this decrease can be approximately described by exponential functions of the time interval. Fig. 1 shows that the time interval between two pulses plays important role: in the case of the real component R, it causes about 30% decrease, whereas in the case of the imaginary component X, the decrease of its absolute value can reach up to about 60%.

Using information from Fig. 1 and paragraph 2.2., we determined for every specimen its initial parameter R_0 that plays key role of the norm for calculation of *R* and *X* after pulsing. In set c only one pulse was applied per specimen, in set d two pulses with an interval between them

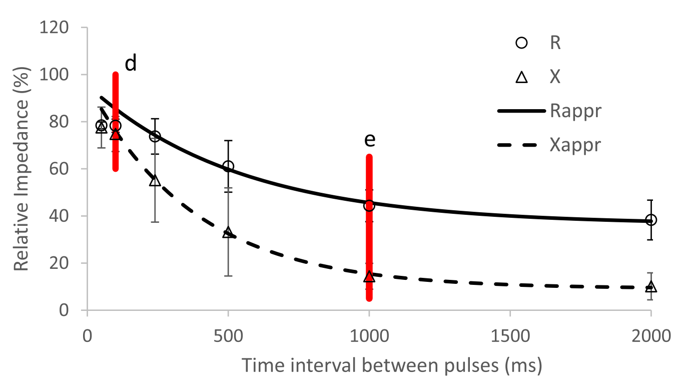

Fig. 1. Plot of tested impedance components after two pulses versus time interval between pulses (variety Dali). The points represent mean values obtained at 5 specimens, the bars denote standard deviations. The obtained data in percent of the initial value are approximated by the exponential equations: Real component $R_{appr} = 36.3 + 59.1 \exp(-0.00185\Delta t)$, Imaginary component: $X_{appr} = 9.16 + 86.88 \exp(-0.00263\Delta t)$, where Δt is time interval between pulses. The symbols d and e denote time intervals corresponding to the sets d and e, respectively.