OBJECTIVE METHOD FOR DETERMINATION OF POTATO COOKING

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ABSTRACT

Cylindrical specimens of 15 mm in diameter and 25 mm in height were prepared from potato tubers by cutting and cooking in a special heating cell at constant temperature (75, 80, 85, 90 and 95°C). The cell was located on the table of an Universal Testing Instron Machine and arranged so that a cooked specimen could be tested repeatedly using non-destructive compression method during the entire cooking process. The sets of the obtained values of Young's modulus form a basis for determination of the cooking depression coefficients and activation energies of the process that controls depression of Young's modulus during cooking.

Keywords

Potato cooking, modulus of elasticity, cooking depression coefficient, activation energy, consistency.

INTRODUCTION

The methods to assess the texture of food products can be divided into two classes: the sensory (subjective) evaluation methods and the instrumental (objective) methods. The sensory evaluation of texture involves taste panels that give their sensory impressions of textural attributes. The numerous methods for objectively measuring the textural properties of foods are classified on the basis of the variables or variables that are the basis of measurement. Scott Blair (1958) classified objective methods of texture measurement under the heading: fundamental, empirical, and imitative. According to Szczesniak (1963), who discussed Scott Blair's classification system in details, the *fundamental test* is a classical material-testing technique used to deform a specimen of defined shape in a specific way so that all test parameters are known and the results can be readily analyzed by rheological theories. In the *empirical* tests the food is subjected to mechanical deformation which applies a sequence or combination of stresses (e.g., compression tension, shear, flow, extrusion) and the sample reaction is recorded. The *imitative tests* are designed to imitate a specific human operation on the food (e.g. biting or squeezing it by hand). These effects can be simulated in special objective tests. In some tests the strain or the deformation produced are measured as a function of stress. Many of these tests may be done by attaching a test cell to a universal testing machine which is a multipurpose instruments that are used to measure the amount of force required to complete a test of the mechanical properties of the test material as well as other parameters.

For instance Kozempel (1988) used a back-extrusion test cell and maximum force readings were taken as a measure of texture of cooked potatoes. Harada et al. (1985) used the maximum shear force to characterize the texture of during cooking. Collison et al. (1980) as well as Verlinden et al. (1995) used a uniaxial compression test in which the rupture force of a potato was taken as a measure of texture. Few fundamental tests such as uniaxial compression, have been reported on cooked potatoes, and most of them measure only fracture stress (Verlinden et al., 1995; Rahadjo and Sastry, 1993). Imitative and empirical tests like Texture Profile Analysis, extrusion tests and puncture tests have been investigated on cooked potatoes (Hughes et al., 1975; Anzaldua-Morales and Bourne, 1992). Although a wide range of special texture measurement devices have been developed and used in literature, all with their own geometrical arrangements, the device which is used in most cases is the so called Universal Testing Machine, which consists of a frame in which a cross-head is moved up and down.

A potato is judged by the cook or consumer to be cooked to an acceptable stage by the assessment, based on their experience, of the force required to insert a pointed knife or a fork. The softening of the tubers so assessed, is the result of the changes in the cell walls induced by higher temperature, the rigidity of the changes being related to the temperature. The texture of cooked potato has often been assumed to be associated with starch content, because starch is the major solid component of the tuber with high dry matter. However, as Linehan and Huges (1969) pointed out, variation in the texture of cooked potatoes can be explained only partly by variations in the starch content of the tuber. Many investigators, e.g. Sterling and Bettelheim (1955), have demonstrated that there are at least two essentially independent features of cooked potato texture. These are referred to as “meanliness” or “mouthfeel” and “breakdown” or “ sloughing”. Mealiness has been shown to be associated with high solids content, high specific gravity, high solids content and relatively low contents of sugars, protein and nitrogen.

Thermal processing of food results in an extended shelf life, but both nutritional and sensorial (texture, color and flavor) qualities are usually damaged to certain level during thermal processing. The optimization of quality is possible because micro-organisms are less thermal resistant than quality factors. Since texture is an important characteristic of vegetables the proper control or modification is needed. Knowledge of physical changes as a function of time and temperature is required to optimize the process conditions. Such information is useful in designing improved thermal processing to maximize quality attributes and to avoid unnecessary overcooking (i.e., undesirable texture, energy wastage, etc.), is of technological and economic importance. Huang and Bourne (1983) studied the kinetics of thermal softening of vegetables and postulated that the rate of softening reflects two simultaneous kinetic mechanisms of the first order: (1) is probably due to the pectic changes in the inter-lamellar layer and accounts for 85-97% of the original tissue firmness. Its relative contribution to firmness decreases practically to zero during processing; (2) a mechanism, whose nature has not been identified, is responsible for the residual firmness of the vegetable after prolonged heating. The first order kinetic model was a much better predictor of textural changes on heating in tissue having thin cell walls (such as those derived from fruits) than in tissue having thick cell walls (such as those derived from stems and roots).

Rao and Lund (1986) gave an overview of the mathematical relations to model the kinetics of thermal softening of foods. A simple and frequently used approach in softening studies has been to express data in terms of an apparent rate constant K:

$$\frac{dX}{dt} = -KX \tag{1}$$

The temperature dependence of the apparent rate constant, was modeled by an Arrhenius type model as:

$$K = K_i e^{-\frac{Ea}{RT}} \tag{2}$$

where E_a is the apparent activation energy, R is the universal gas constant, T the absolute temperature and K_i is the rate constant at infinite temperature. To obtain a more comprehensive physical parameter, the model used in this respect is the following:

$$K = K_{ref}\, e^{-\frac{Ea}{R\left(\frac{1}{T}-\frac{1}{T^{ref}}\right)}} \qquad (3)$$

where K^{ref} is the rate constant at a predefined reference temperature T^{ref}.

This article presents a study of texture kinetics in potato tubers during cooking at constant temperature. The experiments were performed during precise and controlled heating of the specimens in a special cell located at the table of a Universal Testing Machine. During the heating period the modulus of elasticity of the specimen was determined repeatedly and the obtained values contain full information on texture in the test.

MATERIALS AND METHODS

Potato (*Solanum tuberosum L.*) varieties 'Nicola' and 'Panda' were grown at the Potato Research Institute in Havlíèkùv Brod (Experimental Station Valeèov). 'Nicola' belongs to varieties with a lower starch content (about 16-17 %). 'Panda' is a variety with a higher starch content (19-21 %). The tubers were harvested in full maturity at the beginning of October 1998. They were healed three weeks after harvest at 20°C and 95 % relative humidity. Only perfect tubers 55 – 80 mm in diameter were used for experiments. These tubers were stored in boxes at 6°C and 95 % humidity until further testing. They were removed from the box 24 hours before testing. A special laboratory cutter and a cork borer were used for cutting off the cylindrical specimens - 15 mm in diameter and 25 mm in height

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- from central parts of the tested tubers. More information about the tested samples is given in Table 1.

The prepared cylindrical specimen was inserted into a special cooking cell (Fig.1) and compressed repeatedly using an Instron Universal Testing Machine (UTM -Model 4464). The load cell of the UTM is located on the movable cross bar of the machine and was connected directly with the piston of the special cooking cell lying on the supported table of the UTM. Testing conditions were 1 mm compression at a constant deformation rate of 0.167 $mm.s^{-1}$ followed by unloading into initial position using the same deformation rate. The obtained data were recorded by a data acquisition system. After the first measurement at room temperature the cooking cell was heated up to the desired temperature (75, 80, 85, 90 and 95°C).

The tip part (dia. 1.5 mm) of an electronic thermometer was inserted into the central part of the sample to serve as a temperature sensor for checking and controlling the heating process. The cooking cell consisted on thermally isolated heating component (electrical current was regulated by special electronic regulator) and a copper ring (MR) that served as a heat conductor. The first part of the heating period consisted of a step-increase temperature in the cooking cell (one step was about 10°C) up to the desired temperature. The temperature of the central part of the tested specimen was recorded for every specimen; these data later served for calculations of corrections in cooking curves due to pre-heating. When temperature reached the desired value, the compression test of the specimen was performed until it was fully cooked. The temperature was controlled in this part of the test by the regulator at the desired value ± 0.3°C.

The whole process consists of repeated non-destructive deformations of the specimen giving information about its actual mechanical state. Only slopes of the obtained deformation curves were evaluated and the corresponding values of Young’s modulus were calculated from them using the standard software of the Instron UTM. For the cylindrical specimens, Young's modulus (or modulus of elasticity), E, is given by the following formula:

$$E = \frac{l_0}{\pi r^2} \frac{\Delta F}{\Delta x}, \tag{4}$$

where $\Delta F/\Delta x$ is the slope of the deformation curve (the increase of compression force F corresponding to unit increase of deformation x in the linear part of the deformation curve), l_o the initial specimen height and r the initial specimen radius.

Every experimental test conducted in the cooking cell give a time set of Young's modulus. The first results were obtained for a raw specimen tested at room temperature. This value was termed as E_r. Further measurements were performed at the desired cooking temperature. They formed a set with the first member representing the modulus of elasticity of the specimen just after pre-heating. Because the preheating was difficult to be performed repeatedly, especially for different cooking temperatures, it was necessary to correct the experimental data taking into account the pre-heating stage of the experiment. This correction was based on the exponential relation between Young's modulus and cooking time (Blahovec et al., 1998):

$$E = E_0 e^{-kt} \tag{5}$$

where t is cooking time, k cooking depression coefficient (CDC from Blahovec et al., 1998) – or rate constant in Eq.(1) - and E_0 is the value corresponding to zero cooking time. The differential equation corresponding to Eq. (5) is Eq. (1) for X = E and K = k. The corrected value for zero cooking time (E_0), so called initial value of Young's modulus (IVY), at cooking temperature t_d was expressed as:

$$E_0 = E_1 + \int_{t_{70}}^{t_d} k_T E\,dt \qquad (6)$$

where E_1 is the first reading of E, k_T the corresponding value of CDC, t_{70} is time corresponding to temperature 70°C (influence of preheating at lower temperatures is omitted) and t_d is time corresponding to the desired temperature (time of the first compression). This equation was solved numerically; the boundary condition: $E(t_d) = E_1$ was respected and k_T–values were determined by interpolation of the experimental data. The IVY served also as a base for estimation of the second correction parameter, equivalent time shift (ETS), which had to be added to all readings of time in the set:

$$ETS = \ln\left(\frac{E_0}{E_1}\right) / k_d \qquad (7)$$

where k_d is corresponding CDC (at desired temperature).

RESULTS AND DISCUSSION

Only the initial part of the cooking curve, which can be approximated very well by the exponential Eq. (5) - was used for determination of CDC. This is the part of the cooking curves with Young's modulus higher than approximately 1.5 MPa. Coefficients of correlation were usually higher than 0.99 in these cases.

The obtained mean values of CDC are given in Table 2. They are also plotted against reciprocal absolute temperature in Figs. 2 (for 'Nicola') and 3 (for 'Panda'). Figure 2 shows that some deviations from Arrhenius exponential plots were observed for 'Nicola' at low cooking temperatures (75 and 80°C). In case of 'Panda' (Fig. 3) these deviations were not observed.

The results of Arrhenius' rate analysis under Eqs. (2) and (3) are given in Table 3. The table shows that the obtained activation energy is similar to the data given by Rao and Lund (1986). The rate constants are a slightly higher than those given in literature in agreement with our precise evaluation of the process at the beginning of cooking.

But the values of K_i, well higher than 10^{13} (frequency of thermal oscillations), indicate that the thermal softening of the cooked tubers cannot be described by a regular simple thermal activated process (Daniels and Alberty, 1961).

CONCLUSIONS

Young's modulus serves as a good indicator of the actual cooking state of an individual potato specimen. Non-destructive compression deformations that were performed repeatedly during cooking of a potato specimen bring precise information on kinetics of the texture softening. The initial portion of the cooking curve is well described by Eq. (5) with well-defined CDC's (Cooking Depression Coefficient) that follow an Arrhenius type equation (Eq. (2)), at least at higher cooking temperatures. The observed CDC-values of 'Panda' were higher than the CDC-values of 'Nicola' variety. This is an indication of faster cooking rate for 'Panda' in comparison to the 'Nicola' variety. The high rate constants for the softening process form a basis for further speculation on the use of a more complicated character of a model to describe the softening process rather than the simple Arrhenius one.

ACKNOWLEDGEMENT

The paper was supported by the Grant Agency of the Czech Republic through Grant 525/96/1398.

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Table 1 Scheme of the tested samples
(Nor - number of replications, CTm – Cooking time in minutes)

Cooking Temperature (°C)	'Nicola'		'Panda'	
	Nor	CTm	Nor	CTm
November 75	2	265	2	235
80	2	155	2	170
85	3	165	3	165
90	6	64	12	44
95	9	36	7	22
February 75	0	165	2	200
80	0	130	2	100
85	3	75	3	85
90	5	52	7	42
95	6	30	9	22

Table 2 Mean values (MV) and standard deviations (SD) of the CDC values. All values are given in min.$^{-1}$.

	'Nicola'				'Panda'			
Temperature	February		November		February		November	
(^{o}C)	MV	SD	MV	SD	MV	SD	MV	SD
75	-	-	0.01405	0.00045	0.00973	0.00059	0.00911	0.00005
80	-	-	0.01474	0.00314	0.01786	0.00015	0.02285	0.00154
85	0.02879	0.00377	0.01726	0.00181	0.03065	0.00211	0.02699	0.00143
90	0.05172	0.01473	0.04656	0.01114	0.06352	0.00921	0.06898	0.02068
95	0.08471	0.02501	0.06352	0.00956	0.09825	0.01296	0.14548	0.01110

Table 3. Analysis of the data presented in Figs. 2 and 3 (MV – mean value, SD – standard deviation; numbers 1 and 2 denotes November and February results, respectively; R – correlation coefficient)

Parameters	'Nicola' 1 (temp. 85 – 95 C)		'Nicola' 2 (temp. 85 – 95 C)		'Panda' 1		'Panda' 2		Potatoes Rao & Lund (1986)
	MV	SD	MV	SD	MV	SD	MV	SD	MV
R	0.960		0.998		0.984		0.998		
ln K_i	35.2		38.80		44.23				
E_a/R (K)	13966.3		15178.6		17020.6		15114.6		
K_i (s^{-1})	$3.26.10^{13}$	$3.25.10^{13}$	$1.18.10^{15}$	$9.49.10^{14}$	$2.62.10^{17}$	$2.60.10^{17}$	$1.15.10^{15}$	$1.14.10^{15}$	
E_a ($kJ.mol^{-1}$)	116.12	24.02	126.20	4.93	141.52	14.66	125.67	4.43	117.0
K^{100} (s^{-1})	0.00181		0.00255		0.00407		0.00295		
K^{121} (s^{-1})	0.01330		0.02220		0.04630		0.02550		0.00860

Figure Captions

Fig.1. Scheme of the special cooking cell used for cooking of potato samples in Instron universal testing machine. Dark part denotes the heating wires, TI – thermal isolation, C – ceramic parts, MR – metal (copper), P – piston.

Fig. 2. Cooking depression coefficient (CDC) plotted against reciprocal absolute temperature for ‘Nicola’.

Fig. 3. Cooking depression coefficient (CDC) plotted against reciprocal absolute temperature for ‘Panda’.

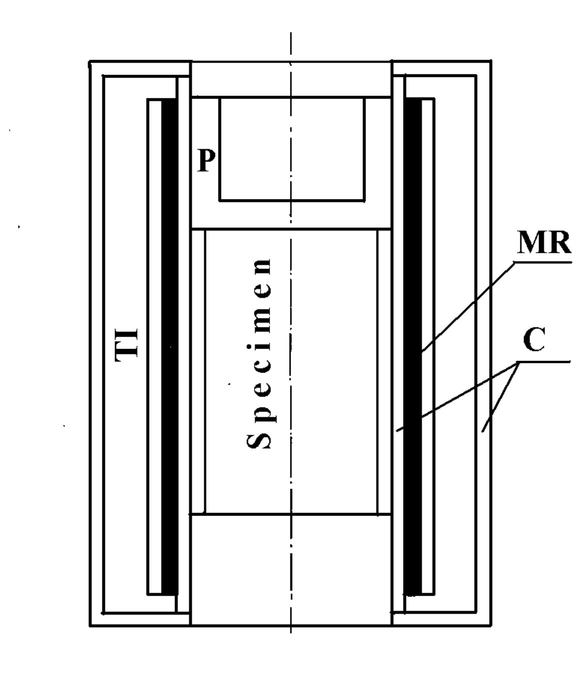

Fig. 1

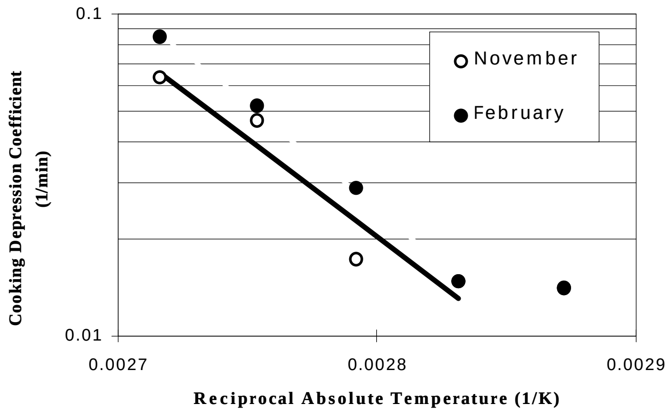
0.1
0.01
0.0027
0.0028
0.0029
Cooking Depression Coefficient (1/min)
Reciprocal Absolute Temperature (1/K)
November
February

Fig. 2

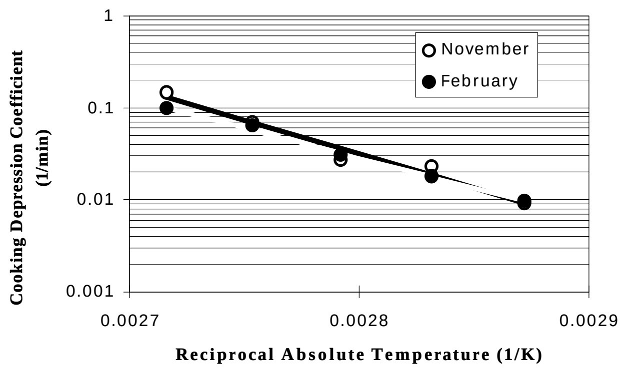

Fig. 3

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LIST OF SYMBOLS

CDC (min^{-1})	- cooking depression coefficient – see Eq. (5)
E (Pa)	- Young‘s modulus
E_a ($J.mol^{-1}$)	- Activation energy –see Eq. (2)
E_r (Pa)	- Young‘s modulus measured at room temperature
E_0 (Pa)	- Young’s modulus at cooking temperature corrected to zero cooking time
E_1 (Pa)	- Young’s modulus at cooking temperature (first reading)
ETS (min)	- equivalent time shift (cooking time at desired cooking temperature having the same softening effect as the real specimen pre-heating)
IVY (Pa)	- initial Young’s modulus – see E_0
k (min^{-1})	- apparent rate constant for Young’s modulus – see Eq. (5)
k_d (min^{-1})	- CDC at temperature t_d
k_T (min^{-1})	- CDC at temperature T
K (min^{-1})	- apparent rate constant in the general form – see Eq. (1)
K_i (min^{-1})	- rate constant at infinite temperature – see Eq. (2)
K^{ref} (min^{-1})	- rate constant at reference temperature (equaled ref) – see Eq. (3)
K^{100}(min^{-1})	- rate constant at reference temperature 100 C
K^{121}(min^{-1})	- rate constant at reference temperature 121 C
l_0 (m)	- initial specimen height
r (m)	- initial specimen radius
R ($J.mol^{-1}.T^{-1}$)	- universal gas constant
t_d (C)	- time of pre-heating up to cooking temperature d
t_{70} (C)	- time of pre-heating up to 70 C