Sloughing in Potatoes Induced by Tuber Density and Affected by Variety

Anna HEJLOVÁ and Jiří BLAHOVEC

Faculty of Engineering, Czech University of Life Sciences Prague, Prague-Suchdol, Czech Republic

Abstract

Hejlová A., Blahovec J. (2008): **Sloughing in potatoes induced by tuber density and affected by variety.** Czech J. Food Sci., **26**: 48–57.

Two cultivars (Nicola and Saturna) largely distinguishing from each other in cooking behaviour and one cultivar (Agria) grown in six different cultivation regimes were tested by the CPEM (cooked potato effective mass) method for the potato sloughing assessment. The sloughing process is characterised by two cooking and disintegration stages, from which two basic CPEM parameters are derived: cooking time as the starting point of disintegration and the rate of the disintegration. Both parameters are analysed as functions of the tuber density in linear models of both stages. Significant differences in CPEM parameters and in the linear models were observed between different varieties. The data from two-year measurements were in basic agreement with our previous concept of the limited contribution of starch in the first cooking stage and of its more important role in the second disintegration stage of sloughing. The results indicated a close association between the mechanisms controlling sloughing and the tuber density in the cultivars Agria and Saturna. A different cooking behaviour was observed in the case of the typical salad cultivar Nicola with a considerably lower cooking time sensitivity to the tuber density.

Keywords: potato; cooking; texture; effective mass; sloughing; disintegration; density

The phenomenon of "sloughing", the flaking and disintegration of the outer layers of potato tubers cooked in water, is considered as one of the principal characteristics of the potato texture (Warren & Woodman 1974). Potatoes are classified into different cooking types which constitute part of the potato texture profile. This simple classification is based on the disintegration ability of cooked tubers with a scale given by two opposite descriptors: salad and sloughed (Vacek 1997).

Potato texture results from many factors, including starch content, cell size, cell-wall composition, starch swelling pressure and breakdown of the cell-wall middle lamella during cooking (Hoff 1973; Jarvis *et al.* 1992; van Marle *et al.* 1994). Among these factors, the tuber density and the degree of disintegration after cooking are often correlated, particularly within one cultivar (Warren & Woodman 1974). This relationship proved to be the most practical for predicting the disintegration degree in potatoes (Matsuura-Endo *et al.* 2002a, b). However, Warren and Woodman (1974) have reported also contradictory results regarding the relationship between the tuber density and sloughing. Similarly, Matsuura-Endo *et al.* (2002a,b) have studied disintegration differences between potatoes with the same starch content which is closely related to the tuber density (van Es & Hartmans 1987).

Partly supported by the Ministry of Education, Youth and Sports of the Czech Republic (Project No. MSM 6046070905).

Different modifications of the sloughing tests associated with the measurements of the degree of cell separation have been used (Woodman & Warren 1972; van Marle *et al.* 1994; Jarvis & Duncan 1992; Freeman *et al.* 1992; Matsuura-Endo *et al.* 2002b). Direct methods for the assessment of sloughing are mostly based on CPM-test (cooked potato mass test) which are also referred as CPW-test (cooked potato weight test) (Böhler *et al.* 1987). During the CPM-test (Anonymous 1977), flakes of potato tissue are cooked in a stirred water bath, then decanted, and the mass of the potato tissue on the sieve is recorded. The characteristic time CT_{100} (the cooking time at which the initial 100 g potato mass remains on the sieve) serves as a measure for the resistance to sloughing.

The CPM-test was modified into the CPEM (cooked potato effective mass) sloughing method in our previous papers (Hejlová *et al.* 2004, 2006). The CPEM method involves cooking the potato flakes on the sieve in a stirred water bath and determining their effective mass periodically during cooking. The method provides two parameters characterising the disintegration process: the cooking time as the starting point of disintegration, and the rate of disintegration. Both parameters can be studied in relation to potato sample density and using close relationships between the tuber density, dry matter, and starch content (von Scheele *et al.* 1937; van Es & Hartmans 1987) also in relation to the starch content. From the data obtained on two cultivars largely distinguishing from each other in the cooking behaviour and one variety grown in different cultivation regimes, the analysis of the role of starch in disintegration process was derived in the previous paper (Blahovec & Hejlová 2006). Our results indicated a minor role of starch in the first part of cooking and its more pronounced role in the second stage of disintegration. This concept was in basic agreement with the results of Jarvis *et al.* (1992) who gave an experimental evidence for the existence of a starch swelling pressure within the cooked potato tissue being large enough to separate the potato cells when the middle lamella has been weakened by pectin degradation.

The same potato groups were tested in the subsequent season. The aim of this paper is to study the influence of the tuber density and of different varieties on the potato disintegration ability. The results are analysed and presented also in relation to our previous measurements and to the previous concept of the role of the tuber density in the disintegration process (Blahovec & Hejlová 2006; Hejlová & Blahovec 2006, 2007).

MATERIAL AND METHODS

Material. The potatoes (cultivars Agria, Nicola, and Saturna) were supplied by the Potato Research Institute, Havlíčkův Brod (Czech Republic), located in the east part of Bohemia. The tubers were grown in six cultivation regimes given by different irrigation levels and by the forms of organic and nitrogen fertilisation (Table 1) (Hejlová & Blahovec 2007; Blahovec 2006a,b), harvested in October 2005 and kept in cold store (at temperature 6°C and 95% humidity) until testing. Cv. Agria tubers were tested in November and December 2005, cvs Nicola and Saturna tubers in January and February 2006.

Potato sample preparation. The potato tuber density was determined by weighing the tubers in air and in tap water considering the water temperature. The margin of error of the test for one tuber was less than ± 2 kg/m^3. For the potato sample preparation, three or four tubers of approximately the same size and mean density were used. The tubers were peeled, cut with a hand

Table 1. Cultivation regimes used for cv. Agria tubers

	Regime					
	1	2	3	4	5	6
Mineral N (kg/ha)	0	120	60 + 60*	60 + 30*	60 + 30*	0
Animal manure (t/ha)	0	30	30	37	37	0
Application form	0	autumn manure**	autumn manure**	spring slurry***	spring slurry***	0
Irrigation	0	0	full	full	saving	full

*organic N added to irrigation, **pig farmyard manure, ***pig slurry

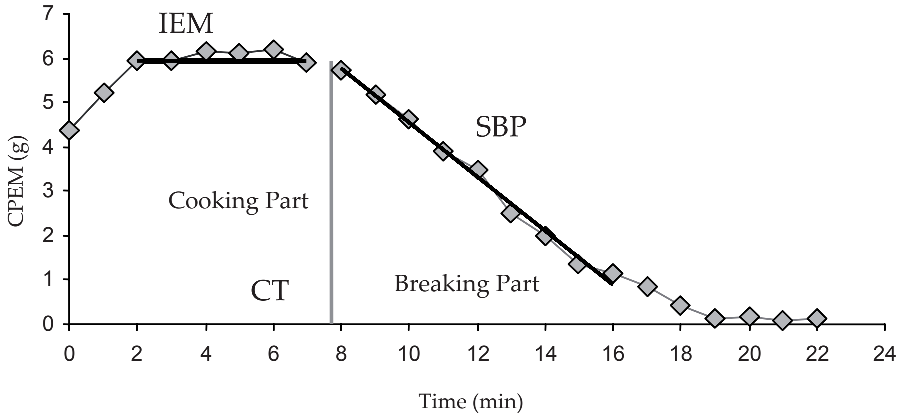


Figure 1. The CPEM curve with definitions of characteristic quantities: secondary parameter IEM, as mean value of the cooking part by excluding the initial 3–4 min; cooking time CT, defined as the time at the intersection of IEM and of the linearly fitted breaking part; slope of the breaking part SBP, defined as the initial slope of the breaking part with the opposite sign

operating kitchen fry cutter into raw chips 10 × 10 mm in cross section. The final product was potato flakes, rectangular slices 1.5 mm thick obtained manually by a special cutter. Immediately before testing the potato pieces were washed on a sieve (15 s) and dried (3–5 min), having been left on a textile tissue at room temperature. The sample, 100 g of washed and dried potato flakes, was then tested by the CPEM method (Hejlová *et al.* 2004, 2006).

CPEM method. The CPEM method (Hejlová *et al.* 2004, 2006; Blahovec & Hejlová 2006) consisted of cooking the potato flakes continuously stirred (750 rpm recommended in Anonymous 1977) in a sieve basket (mesh 2 × 2 mm), and determining their effective mass periodically during cooking. The test was repeated, at least 10 times, with each potato group (i.e. cultivar and regime of cultivation). The cooking and the breaking parts could be distinguished in the final form of the CPEM curve and both parts were approximated by linear functions. Two main parameters were derived: the cooking time (CT) meaning the starting point of disintegration, and the slope of the breaking part (SBP) expressing the disintegration rate (Figure 1).

Evaluation of CPEM parameters. The standard assessment of the CPEM parameters consisted of the evaluation of the mean values and of significant differences between the given potato groups. All statistical results were related to the level 5%.

Table 2. Standard evaluation of basic CPEM data

Potato group	*n*	ρ (kg/m^3)		CT (min)		SBP (g/s)	
		MV	SD	MV	SD	MV	SD
Agria 1	10	1092.20^{a,b}	8.66	5.90^{c}	1.45	0.0108^{h,i,j}	0.0043
Agria 2	11	1083.08^{a}	10.54	8.83^{d,e}	2.70	0.0095^{h,i}	0.0021
Agria 3	10	1091.91^{a,b}	9.89	6.89^{c,d}	1.99	0.0130^{i,j}	0.0037
Agria 4	10	1081.91^{a}	10.20	9.56^{e}	2.41	0.0081^{g,h}	0.0022
Agria 5	10	1081.50^{a}	8.98	8.39^{c,d,e}	2.13	0.0079^{g,h}	0.0017
Agria 6	10	1093.74^{a,b}	7.20	6.67^{c,d}	1.42	0.0132^{j}	0.0028
Nicola	13	1088.21^{a}	9.49	14.99^{f}	1.24	0.0058^{g}	0.0009
Saturna	12	1103.68^{b}	4.82	5.88^{c}	0.87	0.0111^{h,i,j}	0.0013

n – number of observations, MV – mean value, SD – standard deviation, upper indexes denote homogenous classes for the level α = 0.05

Both CPEM parameters were plotted against the tuber density ρ and analysed as functions of density. The cooking stage was described by a set of linear regression equations in individual potato groups creating the linear model of the cooking stage

$$CT = a_{CT} - b_{CT}(\rho - \rho_{MV}) \quad (1a)$$

where: ρ_{MV} – density mean value of all samples tested

The Equation (1a) was transformed into the form (Blahovec & Hejlová 2006)

$$CT = a_{CT0} - b_{CT}(\rho - \rho_0) \quad (1b)$$

where ρ_0 = 1005.46 kg/m^3 is an approximation of the fictive tuber density without starch derived from Scheele's empirical formulas measuring the relationships between potato tuber density, dry matter content, and starch content (von Scheele *et al.* 1937; van Es & Hartmans 1987). Hence the intercept a_{CT0} represents the fictive cooking time required for the sloughing of the potato tissue with zero starch content and is associated with the cell wall properties. The regression coefficient b_{CT} was termed as CT-sensitivity to the starch content in our previous paper (Blahovec & Hejlová 2006).

Similarly, the disintegration stage was described by a set of linear regression equations

$$SBP = a_{SBP} + b_{SBP}(\rho - \rho_{MV}) \quad (2a)$$

and this linear model of the disintegration stage was rewritten into the form

$$SBP = b_{SBP}(\rho - \rho_{ini}) \quad (2b)$$

by computing the additional parameter

$$\rho_{ini} = \rho_{MV} - \frac{a_{SBP}}{b_{SBP}}$$

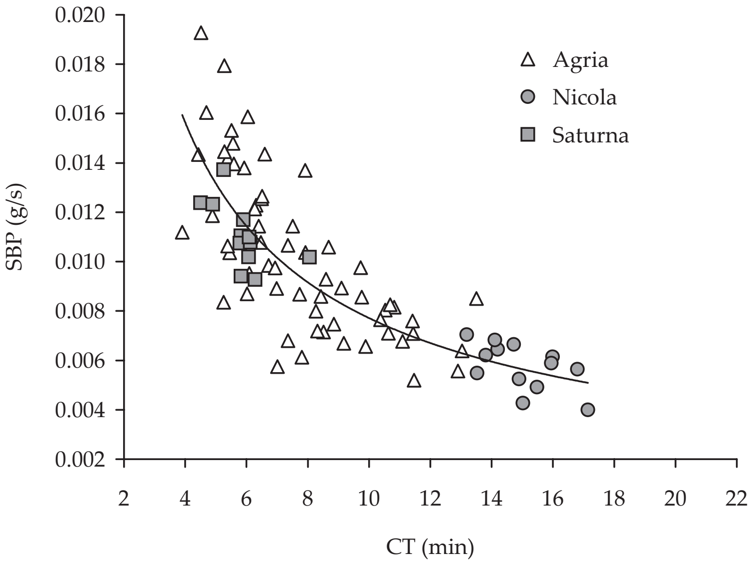
which approximates the fictive density of the potato tissue corresponding to zero disintegration rate (Blahovec & Hejlová 2006).

The possible effects of the cultivation regimes and of different cultivars in association with the tuber density were studied by multiple analysis of variance. More detailed analysis of these effects were focused on the differences between the slopes and intercepts of the corresponding regression lines (Hejlová & Blahovec 2007). From the correlations between the parameters in Eq. (1b) and (2b), the roles of the tuber density and of starch in the disintegration process could be represented (Blahovec & Hejlová 2006).

RESULTS AND DISCUSSION

Basic data evaluation

The basic data obtained in CPEM tests for all varieties are presented in Figure 2 as the dependence of SBP on CT and in Table 2. The salad cultivar Nicola showed considerably higher cooking time CT values and lower SBP values than the mealy cv. Saturna. That lower degree of sloughing in cv. Nicola was accompanied by a significantly lower mean tuber density than in cv. Saturna. The data for cv. Agria are presented and the influence of the cultivation conditions is analysed in another paper (Hejlová & Blahovec 2007).



Data approximated by power function SBP~0.0455 CT$^{-0.771}$, R^2 = 0.703

Figure 2. SBP plotted against cooking time CT

Table 3. Linear models of cooking and disintegration stage

Cultivar	n	a_{CT} (min)		b_{CT} (min m^3/kg)		R^2	a_{CT0} (min)		a_{SBP} (g/s)		$10^6\ b_{SBP}$ (m^3/s)		R^2	ρ_{ini} (kg/m^3)
		Cooking stage*							Disintegration stage**					
		MV	SE	MV	SE		MV	SE	MV	SE	MV	SE		
Agria 1	10	6.68	0.16	0.160	0.017	0.92	19.82	1.50	0.009217	0.001245	0.329	0.130	0.44	1059
Agria 2	11	7.79	0.28	0.244	0.026	0.91	27.78	2.02	0.010270	0.000313	0.178	0.029	0.81	1030
Agria 3	10	7.77	0.23	0.191	0.022	0.90	23.42	1.95	0.011310	0.000320	0.365	0.031	0.95	1056
Agria 4	10	8.37	0.33	0.220	0.030	0.87	26.40	2.32	0.009226	0.000307	0.204	0.028	0.87	1042
Agria 5	10	7.16	0.38	0.213	0.037	0.80	24.55	2.83	0.008657	0.000476	0.135	0.046	0.52	1023
Agria 6	10	7.75	0.34	0.169	0.036	0.73	21.59	3.20	0.010830	0.000447	0.371	0.048	0.88	1058
Nicola	13	14.19	0.26	0.108	0.022	0.68	23.89	1.84	0.006243	0.000266	0.066	0.023	0.43	1001
Saturna	12	7.13	0.27	0.156	0.029	0.75	21.17	2.82	0.009701	0.000610	0.170	0.066	0.40	1038

*See Figure 3a and Eq. (1a, 1b), a_{CT} in Eq. (1a) corresponds to ρ_{MV} = 1087.32 for cv. Agria and to ρ_{MV} = 1095.64 for cvs Nicola and Saturna

**See Figure 3b and Eq. (2a, 2b), a_{SBP} in Eq. (2a) corresponds to ρ_{MV} = 1087.32 for cv. Agria and to ρ_{MV} = 1095.64 for cvs Nicola and Saturna

Linear models of the cooking and disintegration stages

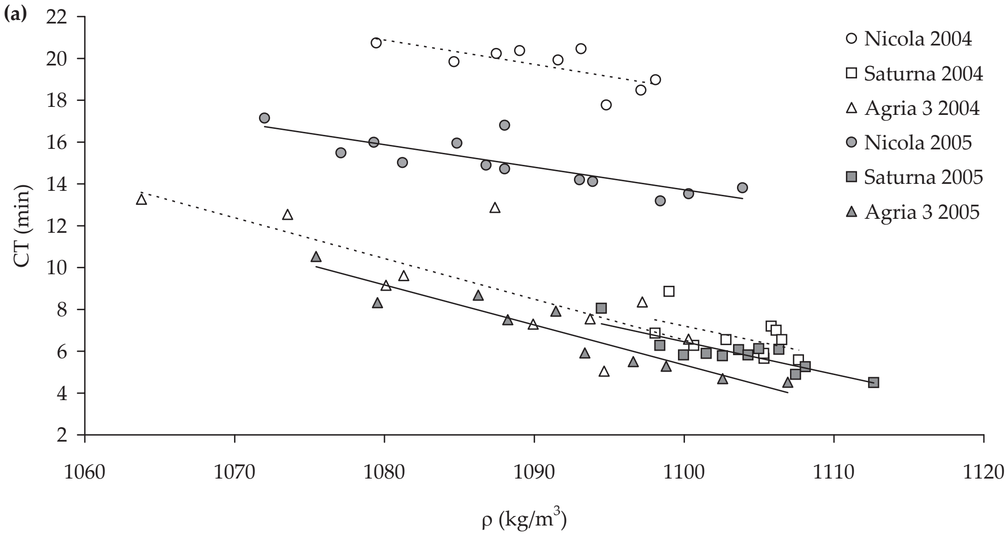
The CPEM parameters for cvs Nicola, Saturna and Agria cultivated in one regime were plotted and analysed as functions of the potato density (Figures 3a, b) and similar data obtained in previous measurements were added (Blahovec & Hejlová 2006). In all potato groups, the CT values decreased with the tuber density while the SBP values increased, in agreement with our previous results (Hejlová *et al.* 2004, 2006; Blahovec & Hejlová 2006) and with the known positive correlation between the sloughing degree and the tuber density within one variety (Warren & Woodman 1974). However, for the same density values evident differences in CPEM parameters between different varieties were present which is in qualitative agreement with other observations (Matsuura-Endo *et al.* 2002a, b).

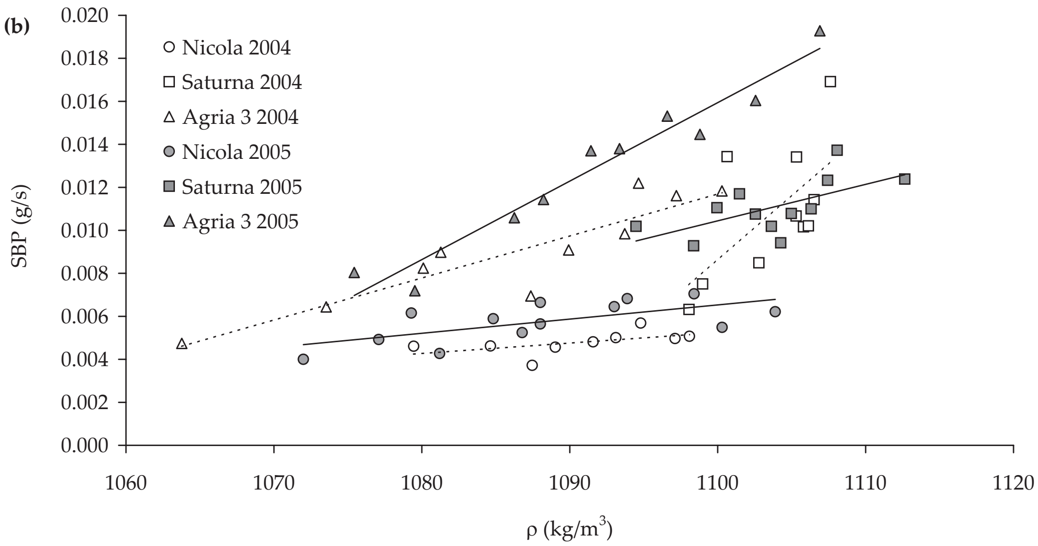
The regression coefficients obtained from the Eqs (1a) and (1b) in Table 3 represented the linear models of the cooking stage. The regression coefficients from the Eqs (2a) and (2b) in Table 3 described the linear models of the disintegration stage in all groups tested. The tubers used for CPEM tests were taken from basic populations (75 tubers at least for each potato group with normally distributed densities) in such a manner that the sample densities were apportioned over the whole range of densities available (Figures 3a, b). The dependence of CPEM parameters on density could be better established in the groups with larger density variations. This fact was reflected

Table 4. Correlation matrices of the parameters describing the dependence of sloughing on tuber density

Data 2004(a)				Data 2005(b)				Data 2004 + 2005(c)			
a_{CT0}	−0.26	−0.83	−0.81	a_{CT_0}	0.67	−0.46	−0.45	a_{CT_0}	0.27	−0.56	−0.51
	b_{CT}	0.43	0.23		b_{CT}	0.22	0.12		b_{CT}	0.31	0.15
		ρ_{ini}	0.94			ρ_{ini}	0.94			ρ_{ini}	0.94
			b_{SBP}				b_{SBP}				b_{SBP}

(a) data see Blahovec and Hejlová (2006); (b) data see Table 3; (c) data see (a) and (b)



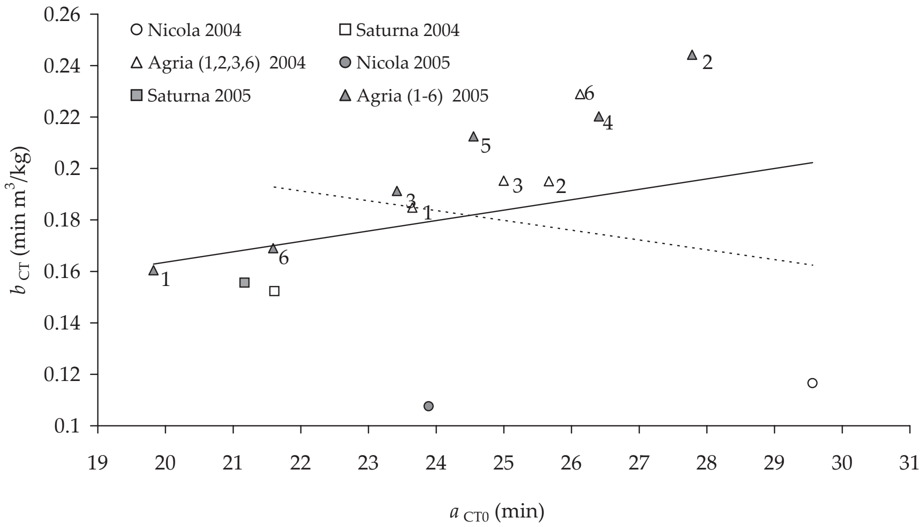


(a) CT plotted against tuber density, regression coefficients from Eqs (1a, 1b) in Table 3, continuous line
(b) SBP plotted against tuber density, regression coefficients from Eqs (2a, 2b) in Table 3, continuous line
Data from the year 2004 added for comparison (Blahovec & Hejlová 2006, dash lines)

Figure 3. CPEM parameters plotted against tuber density

by mostly lower coefficients of determination R^2 in the case of cv. Saturna in comparison to the other cultivars Agria and Nicola in both years (Tables 3 and data in Blahovec & Hejlová 2006).

The differences were assessed between the regression coefficients in both linear models for cvs Nicola and Saturna. The intercepts a_{CT} in the linear model of the cooking stage, which approximated the CT values corresponding to the density mean value ρ_{MV}, were significantly higher with cv. Nicola than with cv. Saturna ($P < 1.11 \times 10^{-13}$). Higher a_{CT0} values approximating the hypothetical CT values corresponding to the potato tissue without starch were also observed with the cv. Nicola. However, this difference was not significant due to the low coefficients of determination in the regression Eqs (1a) and (1b) and due to ρ_0 lying out of the range of the tested sample densities. Similarly, the intercepts a_{SBP} in the model of the disintegration stage differed significantly.



Parameters from Eq. (1b) fitted by the equation $b_{CT} = k\,a_{CT0} + q$, where: $k = -0.0038$ m^3/kg, $q = 0.275$ min m^3/kg, $R^2 = 0.067$ for data from 2004 (dash line); $k = 0.0041$ m^3/kg, $q = 0.083$ min/m^3/kg, $R^2 = 0.075$ for data from years 2004 and 2005 (continuous line, Table 3) (Blahovec & Hejlová 2006)

Figure 4. The regression coefficient b_{CT} plotted against the parameter a_{CT0}

CPEM data in different growing years

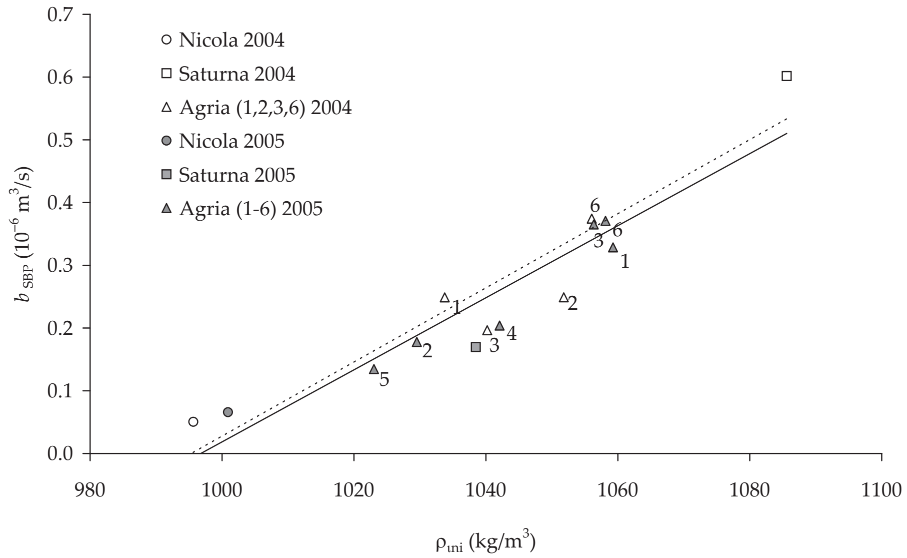
The most pronounced seasonal differences in both CPEM parameters could be seen in the data obtained for cv. Nicola (Figures 3a, b, or compare Table 2 and the data from the previous season 2004–2005 in Blahovec & Hejlová 2006). High CT values for cv. Nicola in the previous season were in qualitative agreement with the results obtained in the primary CPW tests (Anonymous 1977): Vacek (1997) found extremely high characteristic time values for cv. Nicola (32 min) and half these values for cv. Agria (14 min). The CPEM tests of cv. Nicola tubers were performed in the end of January 2005 and in the end of February 2006. Hence the higher degree of sloughing in the second season, i.e. lower CT values and higher SBP values (Figures 3a, b), could be explained by the storage (Warren & Woodman 1974; Alvarez & Canet 2000).

The parallelism of the regression lines for cv. Nicola in the cooking stage in different years (Figure 3a) was confirmed ($P < 0.86$) and a difference in the intercepts was shown ($P < 1.32 \times 10^{-11}$). Similarly, in the case of cv. Saturna the parallelism could be observed ($P < 0.97$) as well as a difference in the intercepts ($P < 0.015$). These facts support our expectations about the regression coefficient b_{CT} to be a relatively stable parameter typical for the variety (Hejlová & Blahovec 2007). Also, in the disintegration stage are the regression lines for cv. Nicola nearly parallel ($P < 0.66$) and shifted ($P < 0.0013$). On the other hand the slopes of cv. Saturna in the disintegration stage differ evidently from each other.

Correlations between parameters describing sloughing

The regression coefficients of the linear models of both cooking and disintegration stages represent a group of parameters describing sloughing in relation to the tuber density and to the starch content. The correlations between these parameters were computed (Tables 4 (a), (b), (c)) and presented in Figures 4 and 5. A correlation between the parameters b_{SBP} and ρ_{ini} ($R = 0.94$ in Table 4) was in a good agreement with the previous results indicating an important role of the starch content in the disintegration stage. The association between a_{CT0} and b_{SBP} was less pronounced (compare with $R = -0.82$ in Table 4).

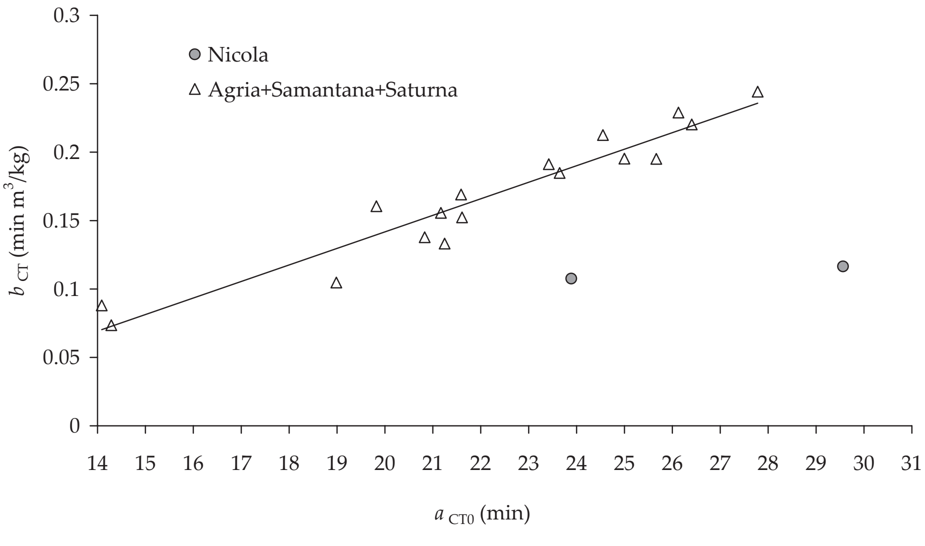
A weak correlation between the parameters a_{CT0} and b_{CT} observed in the previous season ($R = 0.259$ in Table 4) indicated that the starch content plays only a limited role during the first part of cooking that was determined primarily by the basic



Parameters from Eq. (2b) fitted by the equation $b_{SBP} = k\rho_{ini} + q$, where: $k = 5.92\times10^{-9}$ m^3/kg s, $q = -5.89\times10^{-6}$ m^3/s, R^2 = 0.89 for data from 2004 (dash line); $k = 5.74\times10^{-9}$ m^3/kg s, $q = -5.73/10^{6}$ m^3/s, R^2 = 0.88 for data from years 2004 and 2005 (continuous line, Table 3), (Blahovec & Hejlová 2006)

Figure 5. The regression coefficient b_{SBP} plotted against the additional parameter ρ_{ini}

potato characteristics probably related to the cell wall properties. However, our last results showed a better correlation between these parameters ($R = -0.67$ in Table 4). We explain this fact by the limited number of varieties available for the analysis. Cv. Nicola, representing the only not sloughed variety, played the crucial role in the correlation computation in both seasons. Despite the seasonal differences, the correlations between the sloughing parameters obtained from the data of both years 2004 and 2005 were in a good agreement with the previous results (Figures 4 and 5). From this point of view, it can be concluded that the measurements support our concept of the role



Parameters from Eq. (1b) fitted by the equation $b_{CT} = k\,a_{CT0} + q$, where: k = 0.0121 m^3/kg, q = –0.1 min m^3/kg, R^2 = 0.92 for the cvs Agria, Samantana and Saturna (data see in Hejlová *et al.* 2006; Blahovec & Hejlová 2006 and Table 3)

Figure 6. The coefficient b_{CT} plotted against the parameter a_{CT0} and fitted except cv. Nicola

of starch in both stages of potato disintegration (Blahovec & Hejlová 2006).

On the other hand, the same results presented in Figure 4 could be interpreted as a very close relationship between the parameters of the cooking stage for the cultivars Agria and Saturna, and at the same time as an extremely discrepant behaviour of cv. Nicola which causes the loss of correlation between the parameters of the cooking stage. These observations are more pronounced in Figure 6 where the data were added from all CPEM tests performed during three successive years. However, at the same time the disintegration data for cv. Nicola fitted very well into the relationships between the parameters of the disintegration stage for other varieties (Figure 5).

The data presented in Figures 4 and 6 showed that the mechanisms controlling the sloughing process are closely associated with the tuber density in the similar mealy cultivars Agria and Saturna. These relationships probably reflect the stresses in potato cells induced by starch swelling during cooking. In the case of a typical not sloughed cv. Nicola, sloughing was probably controlled by different mechanisms. Our data indicate that the source of the different behaviour of cv. Nicola lies in a lower cooking time sensitivity to the starch content expressed by the regression coefficient b_{CT} and, at the same time, in higher a_{CT0} values which are related to the cell wall properties. However, a detailed explanation of these mechanisms lies beyond the simple linear CPEM model proposed.

CONCLUSIONS

Significant differences in both CPEM parameters, also in association with the tuber density, reflect the known large differences in the cooking behaviour of the tested cvs Nicola and Saturna. The data from two-year measurements support the previous concept of a limited role of starch in the first cooking stage and of its more important role in the second stage of disintegration. It is shown that the mechanisms controlling sloughing are closely associated with the tuber density and the starch content in the potato cvs Agria and Saturna. A discrepant cooking behaviour is observed in the case of the typical salad cv. Nicola.

Acknowledgement. The authors thank to Dr. J. Vacek, Research Potato Institute, Havlíčkův Brod (Czech Republic), for supplying the experimental material of high quality.

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Received for publication February 23, 2007
Accepted after corrections August 16, 2007

Corresponding author:

RNDr. Anna Hejlová, Ph.D., Česká zemědělská univerzita v Praze, Technická fakulta, Kamýcká 129,
165 21 Praha 6-Suchdol, Česká republika
tel.: + 420 224 384 238, e-mail: hejlova@tf.czu.cz