Role of cultivation conditions in potato sloughing as indicated by CPEM method

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ABSTRACT

The new CPEM (cooked potato effective mass) method was used to study the sloughing of a potato variety grown in two successive years in six regimes given by different levels and forms of fertilisation and irrigation. The sloughing process is characterized by the cooking time, i.e. the starting point of disintegration, and by the speed of disintegration. Both parameters are also evaluated in dependence on tuber density in linear models of cooking and disintegration stages. Effects of different cultivation regimes were observed in both stages. The sloughing sensitivity to tuber density expressed via the cooking time seemed to be a relatively stable variety parameter independent of growing conditions. The fertilisation reduced the level of sloughing, i.e. higher cooking time values ($P < 0.0023$), and at the same time lower disintegration rates ($P < 0.006$) were indicated for fertilised tubers. No influence of irrigation was observed in our study.

Keywords: potato; texture; sloughing; disintegration; effective mass; density; cooking time; cultivation; fertilisation; irrigation

The phenomenon of "sloughing", **the flaking and disintegration of the outer layers of potato tubers cooked in water**, is considered to be one of the principal characteristics of potato texture (Warren and Woodman 1974). Potatoes are classified into different cooking types, according to 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).

The potato texture results from many factors, including starch content, cell size, cell-wall composition, starch swelling pressure and the breakdown of the cell-wall middle lamella during cooking (Hoff 1973, McComber et al. 1988, Jarvis and Duncan 1992, Van Marle et al. 1994). Among these factors, the tuber density and the degree of disintegration after cooking have often been correlated, particularly within one cultivar (Warren and Woodman 1974). This relationship proved to be the most practical for predicting disintegration degree in potatoes (Matsuura-Endo et al. 2002a, b). However, Warren and Woodman (1974) also reported contradictory results regarding the relationship between specific gravity and sloughing. Similarly, Matsuura-Endo et al. (2002a, b) studied disintegration differences of potatoes with the same starch content, which is closely related to tuber density and to dry matter content (Van Es and Hartmans 1987).

The effect of cultivation conditions (forms and levels of fertilisation and irrigation) is mostly studied directly in association with yields, dry matter content and potato tuber composition. Increased fertilisation with N decreases the dry matter as a result of postponing maturity (O'Beirne and Cassidy 1990). Westermann et al. (1994a, b) observed the highest tuber density associated with the low N rate (112 kg/ha); nitrogen application above this rate decreased the density. Nitrogen applications reduced dry matter and starch content in both tuber ends, N concentrations in the tuber ends were negatively related to starch. Higher tuber densities were found in samples grown without organic fertiliser independent of storage time (Koch and Damerow 1998).

Dry matter is one of the most important constituents with regard to the texture of potatoes

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(Warren and Woodman 1974, McComber et al. 1988); hence, an influence of nitrogen application on potato texture can be expected. Thybo et al. (2002) observed a significant effect of organic treatments with variation in available N on texture presented by stress and strain in uniaxial compression. Results obtained by Searle et al. (2005) indicate that culinary quality of potatoes can be influenced by crop management. A significant effect of cultivation regimes on the texture of steamed potatoes was observed only in an experiment with the highest nitrogen and irrigation rates. The likelihood of sloughing and mealiness could be predicted from their tuber density. Hegney and McPharlin (2000) found a decrease in potato disintegration with increasing levels of applied N or percent N in tubers; however, the irrigation level had little effect.

The sloughing degree is usually assessed visually (Hegney and McPharlin 2000, Matsuura-Endo et al. 2002a, Searle et al. 2005). Different modifications of sloughing tests associated with measurements of the degree of cell separation were used (Freeman et al. 1992, Jarvis and Duncan 1992, Van Marle et al. 1994, Matsuura-Endo et al. 2002b). Direct methods for the assessment of sloughing are mostly based on **CPM** (cooked potato mass*)* tests, also referred to as **CPW** (cooked potato weight) tests (Bohler et al. 1987). During the CPM test (Anonymous 1977) flakes of potato tissue are cooked in a stirred water bath, decanted, and the potato tissue on the sieve is recorded. The characteristic time $\mathbf{CT_{100}}$ derived from the cooking curve 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 paper (Hejlová et al. 2006). The **CPEM method** involves cooking the potato flakes in a sieve basket in a stirred water bath and determining their effective mass periodically during cooking. The shape of the CPEM curve corresponds to the cooking and disintegration stages of the sloughing process, from which two parameters are derived: cooking time, i.e. the starting point of sloughing disintegration, and speed of disintegration. The CPEM method enables us to study cooking properties in small samples represented only by a few tubers. Thereby a relationship between tuber density and the sloughing process can be analysed in detail (Blahovec and Hejlová 2006).

A potato variety (Agria) cultivated in six different regimes was tested by the CPEM sloughing method. Data from two years of measurements were analysed with the aim to find a possible effect of fertilisation and irrigation factors on the potato disintegration ability.

MATERIAL AND METHODS

Material

The potatoes (variety Agria) were provided by the Potato Research Institute at Havlíčkův Brod, located in the eastern part of Bohemia. The tubers were grown in two successive years (2004 and 2005) in six different cultivation regimes (Blahovec 2005a, b; see also Table 1). They were harvested in October, kept in cold storage (temperature 6°C, 95% humidity) until the end of November, and then they were tested.

Potato sample preparation

The potato tuber density was determined by weighing the tubers twice, in air and in tap water. The inaccuracy of the test for one tuber was less than ±2 kg/m^3. For potato sample preparation, three or four tubers of approximately the same

Table 1. Cultivation regimes used for 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
Grouping by irrigation	W0	W0	W1	n.i.	n.i.	W1
Grouping by fertilisation	F0	F1	F1	n.i.	n.i.	F0

*organic N added to irrigation; **pig farmyard manure; ***pig slurry; n.i. – not involved into the grouping size and mean density were used. The tubers were peeled and cut with a hand-operated 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 one-blade cutter. Right before testing the potato pieces were washed in a sieve (15 sec) and dried (3–5 min) on textile tissue at room temperature. The sample of 100 g of washed and dried potato flakes was then tested by the CPEM method (Blahovec and Hejlová 2006, Hejlová et al. 2006).

CPEM method

The CPEM method (Blahovec and Hejlová 2006, Hejlová et al. 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 (i.e. the difference between the real mass and the corresponding mass of the actual cooking medium) repeatedly during cooking. The test was replicated at least 9 times for every potato group (i.e. regime of cultivation). The **cooking** and the **breaking** parts could be distinguished in the final form of a **CPEM** curve, from which two main parameters were derived: **cooking time (CT)**, i.e. starting point of disintegration; and **slope of the breaking part (SBP***)* expressing the rate of disintegration (Figure 1).

Evaluation of CPEM parameters

Standard assessment of the CPEM parameters consisted in an evaluation of the mean values and of significant differences among the given potato groups using the analysis of variance (Statistica 2000). In this way, the significance of the influence of different cultivation regimes and factors (fertilisation and irrigation) was assessed. The seasonal effect on CPEM data in association with cultivation conditions was assessed by multiple analysis of variance (R Development Core Team 2004).

Both CPEM parameters were plotted against 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 cooking stage:

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

where: ρ_{MV} represents the density mean value of all tested samples. The Eq. (1a) was transformed into the following form (Blahovec and Hejlová 2006):

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

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

The disintegration stage was described similarly by a set of linear regression equations creating the linear model of disintegration stage:

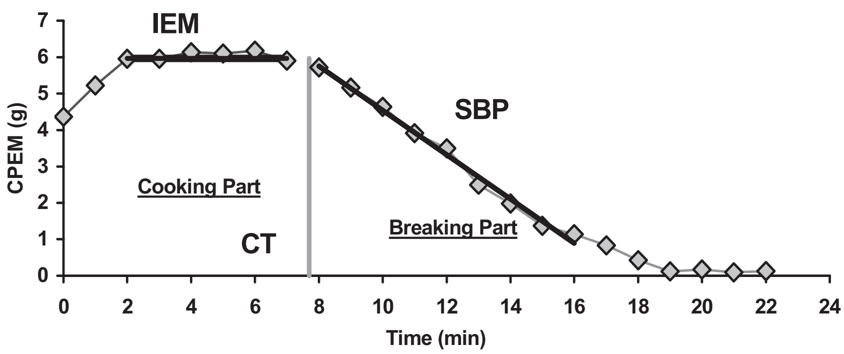

Figure 1. Final form of CPEM curve with definitions of the characteristic qualities: **CT** (cooking time) was defined as the intersection of the **IEM** (initial effective mass) value and the linear approximation of the breaking part by excluding the last part, the **SBP** (slope of the breaking part) was derived as the regression coefficient of the approximation with the opposite sign

Table 2. Standard evaluation of the basic CPEM data

Growing year	Potato group	n	ρ (kg/m³)		CT (min)		SBP (g/s)	
			MV	SD	MV	SD	MV	SD
2004	A1	9	1094.28$^{a, b}$	6.25	7.23^{c}	1.86	0.0150^{g}	0.0027
	A2	10	1096.96^{b}	7.61	7.82$^{c, d}$	1.83	0.0112$^{e, f}$	0.0022
	A3	10	1086.19^{a}	11.49	9.23^{d}	2.84	0.0090^{e}	0.0025
	A4	10	1091.40$^{a, b}$	5.64	6.53^{c}	0.84	0.0130$^{f, g}$	0.0024
	A5	11	1086.43^{a}	5.45	8.33$^{c, d}$	1.48	0.0117$^{e, f, g}$	0.0025
	A6	9	1087.92$^{a, b}$	4.99	7.25$^{c, d}$	1.39	0.0120$^{e, f, g}$	0.0026
2005	A1	10	1092.20$^{a, b}$	8.66	5.90^{c}	1.45	0.0108$^{h, i, j}$	0.0043
	A2	11	1083.08^{a}	10.54	8.83$^{d, e}$	2.70	0.0095$^{h, i}$	0.0021
	A3	10	1091.91$^{a, b}$	9.89	6.89$^{c, d}$	1.99	0.0130$^{i, j}$	0.0037
	A4	10	1081.91^{a}	10.20	9.56^{e}	2.41	0.0081$^{g, h}$	0.0022
	A5	10	1081.50^{a}	8.98	8.39$^{c, d, e}$	2.13	0.0079$^{g, h}$	0.0017
	A6	10	1093.74$^{a, b}$	7.20	6.67$^{c, d}$	1.42	0.0132^{j}	0.0028

Groups according to the Table 1. MV – mean value; SD – standard deviation. Letters in the columns denote the homogenous groups for α = 0.05, data from different years were evaluated separately (Tukey HSD test with unequal number of observations used)

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

The possible effects of cultivation regimes and factors in association with tuber density were studied by multiple analysis of variance. A more detailed analysis of these effects was performed in linear models of both cooking and disintegration stages in which the differences between corresponding regression coefficients and intercepts were assessed (Dalgaard 2002, R Development Core Team 2004). All statistical results were related to the usual level of α = 5%.

RESULTS AND DISCUSSION

Standard evaluation of CPEM parameters

An evaluation of the mean values and of the differences among potato groups is given in Table 2

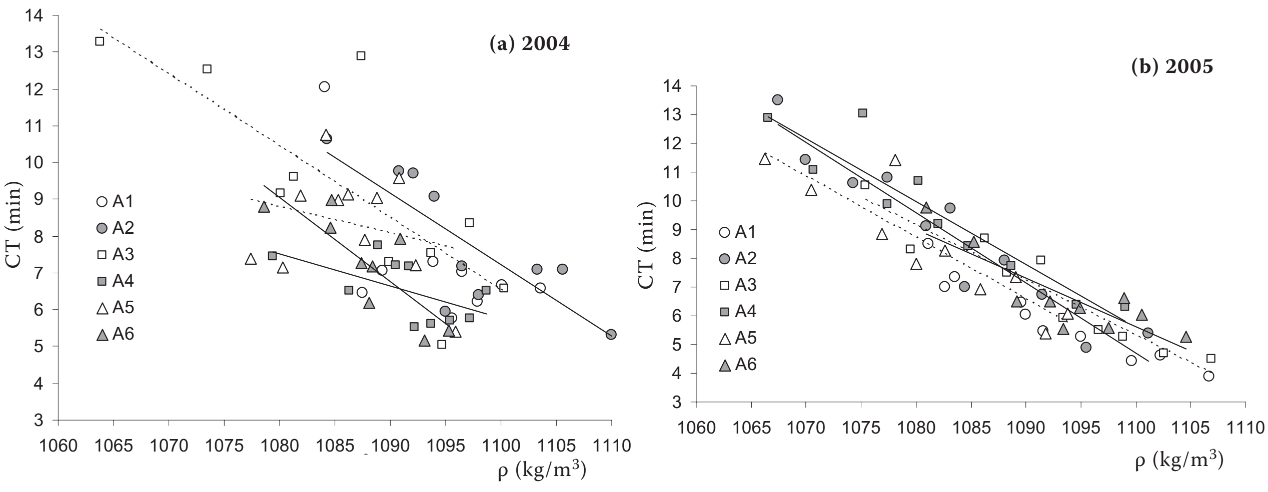

Figure 2. Linear model of cooking stage, CT plotted as a function of tuber density and approximated by Eq. (1a), (1b); the regression coefficients are given in Table 3; (a) growing year 2004, (b) growing year 2005

with statistically significant results. The minimal degrees of sloughing, i.e. the highest CT and at the same time the lowest SBP values, were found in the potato group A3 in the year 2004, and in the group A4 in 2005; in both cases it was in a fertilized and irrigated group (see Table 1) and a lower degree of sloughing was accompanied by lower tuber densities.

CPEM parameters as functions of tuber density

The CPEM parameters were plotted against potato density and the individual plots were evaluated as linear functions of tuber density ρ (Figures 2 and 3). The regression coefficients obtained from the equations (1a) and (1b) are given in Table 3 and represent the linear models of the cooking stage. The regression coefficients from the equations (2) in Table 4 describe the linear model of the disintegration stage of sloughing.

The cooking time **CT** decreased with increasing tuber density (Figure 2a, b) and the disintegration rate **SBP** increased with tuber density (Figure 3a, b) in all potato groups and in all cultivation regimes. The SBP and CT values were negatively correlated in all groups (with the values of correlation coefficient R between −0.53 and −0.91), i.e. a lower degree of sloughing was associated with longer cooking times and slower disintegration. This correlation between the degree of sloughing and tuber density is in agreement with similar results observed within one cultivar (Warren and Woodman 1974, Matsuura-Endo 2002a, b).

Effect of different cultivation regimes

A significant influence of different cultivation regimes on both sloughing parameters and on tuber densities resulted from the standard evaluation of CPEM data as shown above (Table 2). A seasonal effect in association with cultivation conditions could be proven for tuber density ($P < 0.044$) and for disintegration rate SBP ($P < 0.0029$) but not in the case of cooking time CT ($P < 0.93$).

Both CPEM parameters were influenced by different cultivation regimes also in association with tuber density. Multiple analysis of variance showed a significant effect on the CT values ($P < 0.002841$ in 2004, $P < 0.000912$ in 2005) and on the SBP values ($P < 2.6 \times 10^{-7}$ in 2004, $P < 0.00397$ in 2005).

A more detailed analysis of the linear models of the cooking stage focused on the differences between the slopes and between the intercepts of regression lines in given potato groups (see Table 3 and Figure 2a, b). No significant difference among the slopes of individual regression lines was proven in these models. Some differences in the intercepts of these lines were shown (see also Table 6).

The regression coefficient b_{CT} was described as CT-sensitivity to tuber density and starch content (Blahovec and Hejlová 2006). Our results indicated that b_{CT} represents relatively a stable parameter typical for the variety, independent of cultivation conditions. The intercepts a_{CT} in Eq. (1a) are approximations of cooking time required for the start of disintegration of potato tissue with mean density. This parameter was significantly influenced by different cultivation conditions. The intercepts

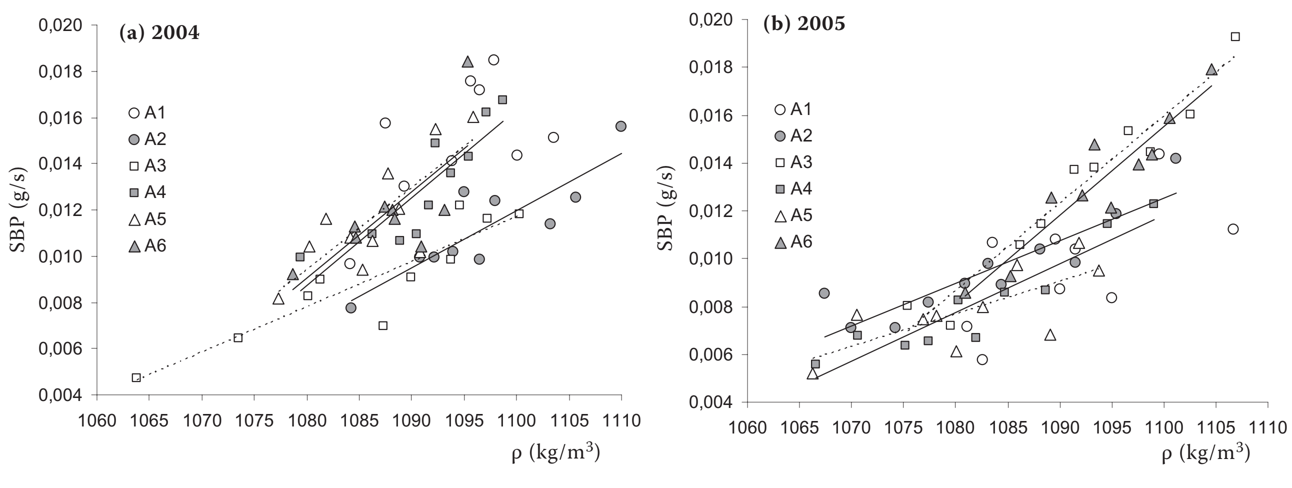

Figure 3. Linear model of disintegration stage, SBP plotted as a function of tuber density and approximated by Eq. (2); the regression coefficients are given in Table 4; (a) growing year 2004, (b) growing year 2005

Table 3. Linear models of cooking stage, regression coefficients from Figure 2a, b

Growing year	Potato group	n	a_{CT} (min)		b_{CT} (min.m^3/kg)		a_{CT0} (min)		R^2 (–)
			MV	SE	MV	SE	MV	SE	
2004	A1	9	7.95	0.62	0.19	0.090	23.74	7.84	0.39
	A2	10	9.09	0.48	0.195	0.049	25.62	4.55	0.66
	A3	10	8.40	0.63	0.195	0.054	25.00	4.36	0.62
	A4	10	6.61	0.23	0.09	0.042	14.07	3.63	0.35
	A5	11	8.04	0.57	0.07	0.0870	14.17	7.06	0.07
	A6	9	6.67	0.32	0.23	0.060	26.13	5.01	0.67
2005	A1	10	6.68	0.16	0.16	0.02	19.82	1.50	0.92
	A2	11	7.79	0.28	0.24	0.03	27.78	2.02	0.91
	A3	10	7.77	0.23	0.19	0.02	23.42	1.95	0.90
	A4	10	8.37	0.33	0.22	0.03	26.40	2.32	0.87
	A5	10	7.16	0.38	0.21	0.04	24.55	2.83	0.80
	A6	10	7.75	0.34	0.17	0.04	21.59	3.20	0.73

n – number of observations; a_{CT}, b_{CT}, a_{CT0} – coefficients from equation (1a, b); SE – standard error; R^2 – coefficient of determination

2004: ρ_{MV} = 1090.4 kg/m^3, differences among the intercepts a_{CT} were shown, differences among b_{CT} were not proven ($P < 0.6$)

2005: ρ_{MV} = 1087.3 kg/m^3, differences among the intercepts a_{CT} were shown, differences among the slopes b_{CT} were not proven ($P < 0.29$)

Table 4. Linear models of disintegration stage, regression coefficients from Figure 3a, b

Growing year	Potato group	n	a_{SBP} (g/s)		b_{SBP} (10^{-6} m^3/s)		R^2 (–)
			MV	SE	MV	SE	
2004	A1	9	0.01405	0.00094	0.251	0.134	0.33
	A2	10	0.00961	0.00050	0.249	0.052	0.74
	A3	10	0.00981	0.00038	0.196	0.032	0.82
	A4	10	0.01266	0.00040	0.380	0.074	0.77
	A5	11	0.01308	0.00061	0.350	0.094	0.61
	A6	9	0.01292	0.00072	0.374	0.135	0.52
2005	A1	10	0.0092	0.0012	0.33	0.13	0.44
	A2	11	0.0103	0.0003	0.18	0.03	0.81
	A3	10	0.0113	0.0003	0.37	0.03	0.95
	A4	10	0.0092	0.0003	0.20	0.03	0.87
	A5	10	0.0087	0.0005	0.14	0.05	0.52
	A6	10	0.0108	0.0004	0.37	0.05	0.88

n – number of observations; a_{SBP}, b_{SBP} – coefficients from regression equation (2)

2004: ρ_{MV} = 1090.4 kg/m^3, differences among the intercepts a_{SBP} were shown, differences among the slopes b_{SBP} were not proven ($P < 0.387$)

2005: ρ_{MV} = 1087.3 kg/m^3, differences in both coefficients were shown, differences among the slopes b_{SBP} were proven ($P < 0.02$)

Table 5. Cultivation factors in mean value evaluation of CPEM data

Growing year	Group	n	ρ (kg/m^3)		CT (min)		SBP (g/s)	
			MV	P-value	MV	P-value	MV	P-value
2004	**F0**	18	1091.09	0.8704	7.24	0.0661	**0.0135**	**0.0006**
	F1	20	1091.58		8.52		**0.0101**	
	W0	19	**1095.69**	**0.0018**	7.54	0.2894	**0.0130**	**0.0106**
	W1	19	**1087.00**		8.29		**0.0104**	
2005	**F0**	20	1092.97	0.0639	**6.28**	**0.0170**	0.0120	0.4520
	F1	21	1087.28		**7.90**		0.0112	
	W0	21	1087.42	0.0790	7.43	0.3479	**0.0101**	**0.0060**
	W1	20	1092.83		6.78		**0.0131**	
2004 + 2005	**F0**	38	1092.08	0.1963	**6.74**	**0.0023**	**0.0127**	**0.0060**
	F1	41	1089.37		**8.21**		**0.0107**	
	W0	40	1091.35	0.5242	7.48	0.9530	0.0115	0.7193
	W1	39	1089.99		7.51		0.0118	

Grouping according to the cultivation factors see Table 1. P-values resulted from t-tests of mean value assessments. Significant differences are marked bold

a_{CT0} in the modified Eq. (1b) can be interpreted as approximations of fictive cooking time corresponding to potato tissue without starch, which is related to the cell wall properties (Blahovec and Hejlová 2006). No statistically significant differences among these parameters could be observed directly, due to the value of ρ_0 lying outside the actual range of tuber densities and due to the low coefficients of determination in individual regression lines (Table 3). Nevertheless the a_{CT0} values and the previous analysis indicated variability in this parameter.

A similar statistical analysis was applied to linear models of disintegration stage in individual years (Table 4 and Figure 3a, b). An influence of cultivation factor on the slopes b_{SBP} ($P < 0.054$) was indicated from two years' data. In contrast to the cooking part, the disintegration part of a CPEM test was affected by the test condition, especially by the stirrer (Blahovec and Hejlová 2006, Hejlová et al. 2006). Hence the previous relative independence of the parameter b_{CT} on cultivation conditions seems to be more relevant.

Fertilisation and irrigation effects

In the selected groups A1, A2, A3 and A6 the cultivation regimes followed two cultivation factors, fertilisation and irrigation (see Table 1). Possible effects of these cultivation factors were studied only in these groups. The effects of cultivation factors in mean value evaluation of CPEM data are given in Table 5. Data from both years show significantly higher degree of sloughing (i.e. less CT values and higher SBP values) for samples taken from tubers grown without fertilisation. An effect of irrigation (if it exists) was not proven.

Similar effects were also observed for density in data from both growing years (Figures 4 and 5, Tables 6 and 7). The effect of fertilisation was more pronounced in the linear model of cooking stage than in the disintegration stage. For the same density, lower CT values could be expected for unfertilised tubers. An effect of irrigation (if it exists) could not be proven in these linear models.

To sum up, in the case of Agria variety, the fertilisation factor caused lower disintegration levels, i.e. higher CT values and lower SBP values, whereas the irrigation effect was weaker. A similar relationship was observed by Hegney and McPharlin (2000) where the level of disintegration was assessed on a standard five-point scale. Our results were in qualitative agreement with data obtained by Searle et al. (2005) and by Thybo et al. (2002). The lower degree of sloughing for fertilised tubers could be explained by the nitrogen application and concentration, which might reduce starch content and potato tuber density (O'Beirne and

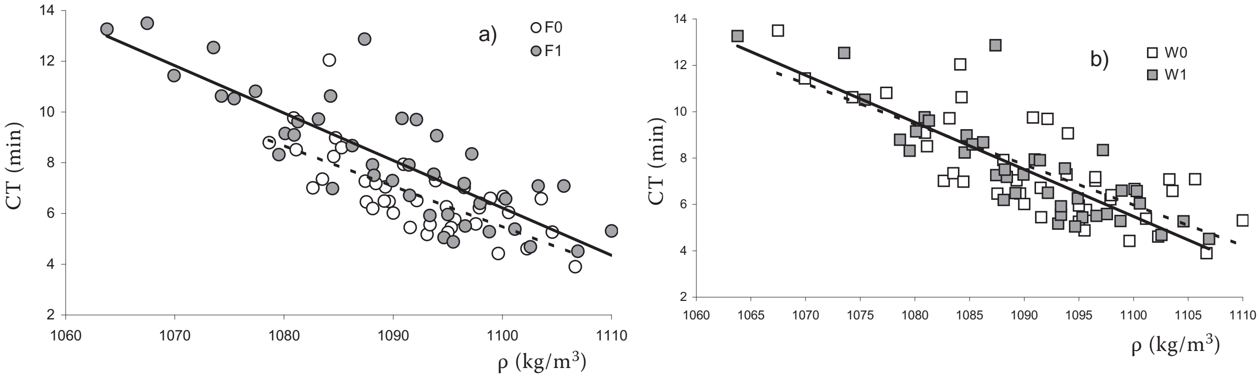

Figure 4. Cultivation factors in the cooking stage, CT plotted as a function of tuber density and approximated by Eq. (1a), (1b); the regression coefficients are given in Table 6; (a) effect of fertilisation, (b) effect of irrigation

Cassidy 1990, Westermann et al. 1994a, b, Thybo et al. 2002) and by the known relationship between disintegration level and tuber density (Warren and Woodman 1974).

Finally, it can be concluded that cooking time CT decreases and disintegration rate SBP increases with increasing tuber density in all cultivation regimes used for Agria, in accordance with the known correlation between disintegration level and tuber density. When the relationships of CT and SBP versus tuber density are described linearly, the cultivation regimes cause differences among the intercepts in these relations. A variation of the slopes due to the cultivation regimes was not observed in our study. Application of organic and N fertiliser causes an increase in CT values and a decrease of SBP values, i.e. a lower degree of sloughing. This CPEM result is in agreement with the knowledge that applications of nitrogen fertilisers reduce starch content and tuber density. The irrigation effect (if it exists) is weaker than the effect of fertilisation.

Table 6. Cultivation factors in linear models of cooking stage

Group	n	a_{CT} (min)		b_{CT} (min.m^3/kg)		R^2 (–)
		MV	P-value	MV	P-value	
F0	38	6.96	0.0008	0.160	0.439	0.53
F1	41	7.96		0.187		0.70
W0	40	7.60	0.455	0.176	0.402	0.59
W1	39	7.37		0.203		0.70

Coefficients from Eq. (1a, b); data from both years 2004 and 2005; ρ_{MV} = 1090.1 kg/m^3; P-values assessed the differences between the slopes and intercepts of regression lines in corresponding linear models (Figure 4a, b)

Table 7. Cultivation factors in linear models of disintegration stage

Group	n	a_{SBP} (g/s)		b_{SBP} (10^{-6} m^3/s)		R^2 (–)
		MV	P-value	MV	P-value	
F0	38	0.0123	0.0088	0.332	0.080	0.47
F1	41	0.0110		0.229		0.70
W0	40	0.0114	0.2030	0.233	0.122	0.44
W1	39	0.0120		0.317		0.74

Coefficients from Eq. (2); data from both years 2004 and 2005; ρ_{MV} = 1090.1 kg/m^3; P-values assessed the differences between the slopes and intercepts of regression lines in corresponding linear models (Figure 5a, b)

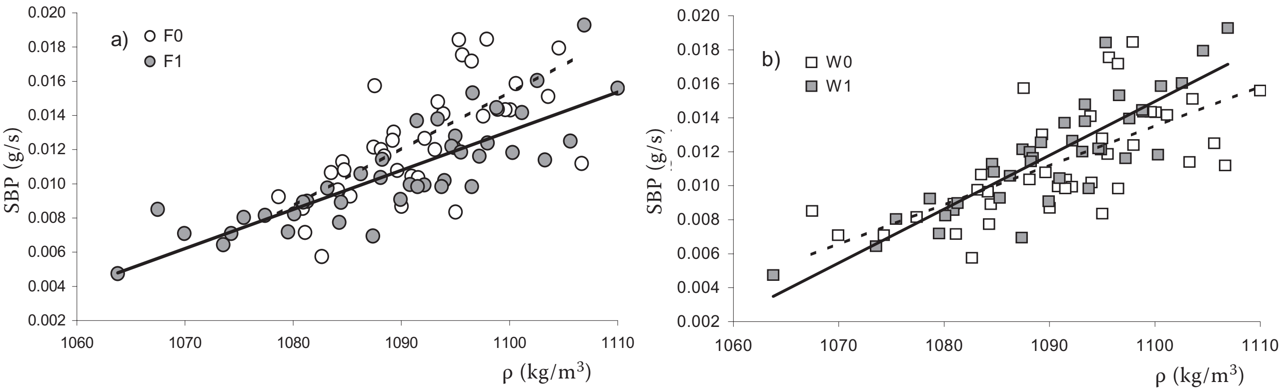

Figure 5. Cultivation factors in the disintegration stage, SBP plotted as a function of tuber density and approximated by Eq. (2); the regression coefficients are given in Table 7; (a) effect of fertilisation, (b) effect of irrigation

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