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Density and shape characteristics of Agria tubers cultivated at different conditions

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ABSTRACT: Potato variety Agria was cultivated in different fertilising and/or irrigation regimes. Individual tuber dimension and the individual tuber density were studied two months after the harvest with aim to find some potential relation between tuber density and its shape. The stem-bud density gradient was also studied by determination the density of the stem, middle and bud parts of the individual tubers. The results of the measurements brought information on relatively variable parameters that slightly depended on the cultivation conditions.

Keywords: potato; density; stem; bud; cultivation regime; shape factor; elongation, flatness

Potato reacts sensitively on fertilising level, water availability, temperature, soil conditions and other details of cultivation methods. The tuber yield, shape of tubers, tuber density and/or their composition are sensitive indicators of the changes of the cultivation conditions (Burton 1966; Hughes 1979; Pazourek 1980; Rybáček et al. 1988; Reeve et al. 1971, 1973a,b; Stark, Love 2003; Hamouz et al. 2000). Tuber shape and starch content are the most sensitive indicators of these changes. The starch content is also one of the most important factor of the potato cooking quality (Van Es, Hartmans 1981; Hejlová et al. 2004a,b). The starch content and the dry matter content are very tightly intercorrelated with the tuber density. This is why the tuber density is frequently used for estimation of the potato starch content using the simple and reliable method of double weighting of potatoes (Van Es, Hartmans 1981), in air and in water. The original Archimedes formula for potato density ρ is expressed in the following form (Van Es, Hartmans 1981; Mohsenin 1970):

$$\rho = \rho_v \frac{m}{m - m_{UWW}} \quad (1)$$

where: ρ_v – water density at temperature of measurement,

m – potato mass determined by weighting in air,

m_{UWW} – potato mass determined by under water weighting.

The method is so simple and exact enough that makes possible to determine density of the individual tubers and their parts as well.

Generally, the irregularities in the tuber growing lead to tuber shape deformations as well as to changes in the tuber density (Burton 1966). The natural density gradients (radial and axial – see Burton 1966 or Van Es, Hartmans 1981) are also modified and/or changed by the tuber growing irregularities.

In this paper the individual tuber densities, their axial density gradients, their shape geometry are studied for variety Agria cultivated in different regimes, i.e. with different levels of fertilisation and irrigation.

MATERIALS AND METHODS

The variety Agria cultivated in six different regimes was tested two months after harvest. The regimes of the potato cultivation are given in Table 1. The whole field experiment was organised on the experimental station Valečov (Research Potato Institute) close to Havlíčkův Brod in the Eastern Bohemia. The tubers were cold stored in an air ventilated room at 6–10°C. After transport the tubers were stored in a refrigerator for a few days at (7 ± 1) °C. The day prior to testing the tubers were washed in cold water and then 50 defect-free tubers of mediate size (5 to 8 cm in diameter) were selected for the test.

The test was performed steeply for groups of 10 tubers. The main dimensions, i.e. length a as maximum dimension in stem-bud direction, width b, and thickness c, of every tuber were determined. The width and thickness are measured in dimension perpen-

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Table 1. Cultivation regimes

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		autumn	autumn	spring	spring	
form		manure**	manure**	slurry***	slurry***	
Irrigation	0	0	full	full	saving	full

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

dicular to the potato axis of length *a* in so manner that $b > c$. The mean tuber density was determined by weighting tuber in air and in water at temperature 20 ± 1°C, using Eq. (1). The same results were used to determination of the tuber volume *V*:

$$V = \frac{m - m_{UWW}}{\rho_v} \tag{1a}$$

The length of every tuber were than divided into three approximately the same parts and these parts were separated by cutting perpendicularly to the tuber axis. The obtained parts were than denoted as stem (S) middle (M), and bud (B) ones. For every part the measurement of the density was reproduced so that not only density, but also their mass and volume were determined. The mass and volume data were used for checking the obtained results.

The shape of the tuber was rationalised by three separate parameters. The first one, termed as the shape factor (*SF*), expresses tuber shape difference from the tri-axial ellipsoid. It was calculated under the following formula:

$$SF = \frac{6V}{\pi abc} \tag{2}$$

The shape factor of an ellipsoidal tuber is one; overstepping the theoretical ellipsoidal surface by the real tuber surface the shape factor *SF* increases and *vice versa*. The further term is tuber elongation *EL*:

$$EL = \frac{2a}{(b + c)} \tag{3}$$

The last shape parameter is flatness *F*, the ratio c/b.

The density of tuber parts was used for indexing the tuber homogeneity via ratios:

$$I_{kl} = \frac{\rho_k}{\rho_l} \tag{4}$$

for the following subscript couples *kl*: MS, MB, and SB, where M, S, and B denote the middle part, the stem part, and the bud part, respectively.

RESULTS AND DISCUSSION

Tuber density

The results obtained for tuber density are plotted in Table 2. The table shows that the mean density of the tested tubers is comparable for all the cultivation regimes. This conclusion is in qualitative agreement with the previous results (Blahovec, Židová 2004; Hejlová et al. 2004a,b). Table 2 contains some differences in the density standard errors (SE). Even if the both the Lavene's and the Brown-Forsythe's tests classified this difference as not significant, the standard errors well correlate with the minimal measured density values increasing from 1,054 kg/m^3 (regime 5) to 1,078 kg/m^3 (regime 1). It seems that

Table 2. Mean tuber density and their homogenity ratios

Regime	Density* (kg/m^3)		I_{MS}		I_{MB}		I_{SB}	
	MV	SE	MV	SE	MV	SE	MV	SE
1	1,093.5	0.7	1.0030^{a}	0.0005	1.0043^{b,a}	0.0004	1.0013^{b}	0.0008
2	1,093.9	1.3	0.9973^{b}	0.0015	1.0078^{a}	0.0016	1.0107^{a}	0.0032
3	1,092.9	0.9	1.0020^{a}	0.0006	1.0078^{a}	0.0005	1.0058^{a}	0.0010
4	1,092.2	1.2	1.0003^{a}	0.0017	1.0088^{a}	0.0017	1.0087^{a}	0.0026
5	1,092.0	1.5	1.0031^{a}	0.0007	1.0054^{a,b}	0.0006	1.0023^{b}	0.0011
6	1,091.1	1.1	1.0043^{a}	0.0005	1.0013^{b}	0.0005	0.9971^{b}	0.0008

Results of Tukey tests on 0.05% level of significance; *no significant difference; other superscripts of the same letter denotes values without significant difference; MV – mean value, SE – standard error

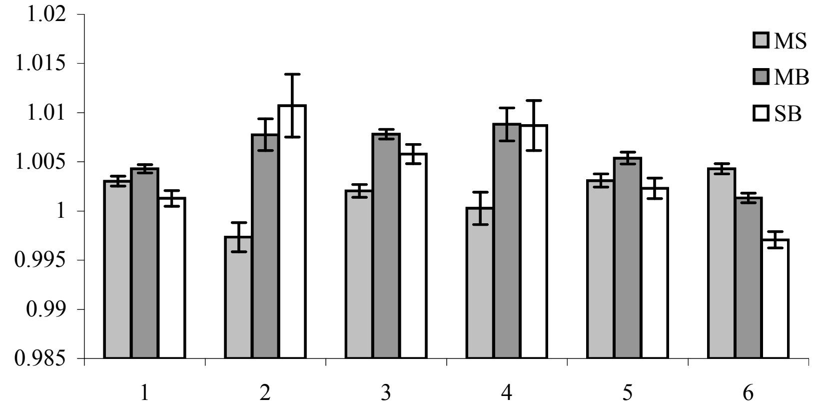

Fig. 1. Mean values of the homogeneity ratios of tubers cultivated at the six regimes of cultivation (horizontal axis). There are plotted ratios of the densities determined for middle part (M), stem part (S) and bud part (B) of the tuber. The bars denote standard errors (see Table 2)

the obtained different SE values are given by different proportion of the low value results for different regimes of cultivation.

The homogeneity ratios in Table 2 gave information about non-monotony character of axial density gradient in the tested potato tubers. Mean values of the ratios I_{MS} and I_{MB} in Table 2 are higher than 1 (with one exclusion) and it means that mean density of the middle part was higher than mean density of the other parts of the tubers. The exclusion for middle-stem relation was observed for the well fertilised but non-irrigated case 2, for which little higher mean tuber density was observed in agreement with the previous results (Blahovec, Židová 2004). Only in this case the classical monotonic decreasing axial stem-bud density gradient was observed. The mean gradient of density between stem and bud is the highest from all the inspected cases (I_{SB}) in Table 2 represented by the density decrease in a tuber in average about 11 kg/m^3. The similar but not so strong trend was observed also for the fertilised and the irrigated plants cultivated in the regimes 3 and 4, with I_{SB} denoted by the superscript *a* in Table 2. The same information in graphical form is also given in Fig. 1. The opposite trends was observed for regimes 6, 1, and partly 5 (see also Fig. 1), in which density decreased (regime 6) or its constancy (1, 5) was a characteristic property of the axial stem – bud direction. Two of the cases (1, 6) represented the regimes without any fertilisation.

Tuber shape parameters

The shape parameters of the tested tubers were variable, coefficient of variation was approximately the same for all regimes of cultivation: 5% for the shape factor, 9% for the tuber elongation and about 7% for the flatness. This variation caused that no significant regime dependent differences in the shape parameters were observed (Table 3). Anyway some details in the shape parameters statistic indicated grow differences in potato tubers cultivated in different cultivation regimes (Fig. 2), in which the *SF* distribution curves for the cultivation regimes 4 and 2 are plotted. On the both curves some steps at *SF* between 1.01 and 1.04 were observed, but in the regime 4 the step represented more than 2/3 of the measured tubers in contrary to only 25% in the regime 2 and similarly also in the regimes 3 and 5. The other two regimes (1 and 6) are intermediate to these two described extremes. These results will be verified in the future research with higher number of specimens.

Table 3. Mean tuber shape parameters

Regime	Shape factor*		Elongation*		Flatness*	
	MV	SE	MV	SE	MV	SE
1	1.0365	0.0058	1.462	0.018	0.8450	0.0069
2	1.0392	0.0076	1.495	0.022	0.8432	0.0084
3	1.0267	0.0075	1.518	0.017	0.8363	0.0083
4	1.0197	0.0085	1.487	0.019	0.8356	0.0085
5	1.0292	0.0075	1.515	0.019	0.8303	0.0090
6	1.0286	0.0060	1.439	0.017	0.8447	0.0085

Results of Tukey tests on 0.05% level of significance; *no significant difference, MV – mean value, SE – standard error

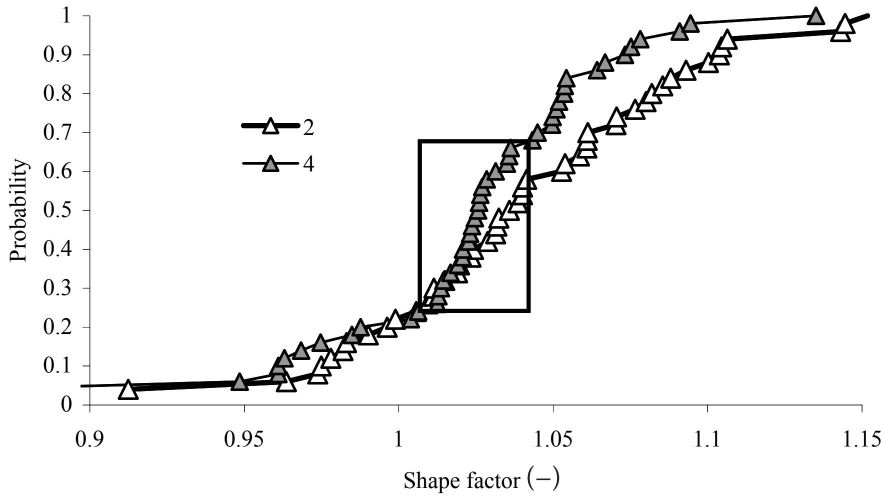

Fig. 2. Probability of the shape factor to be less than characteristic value given by the obtained data for the regimes of cultivation 2 (MV: 1.0392) and 4 (MV: 1.0197). The frame denotes characteristic step on the curves for the shape factors between 1.01 and 1.04

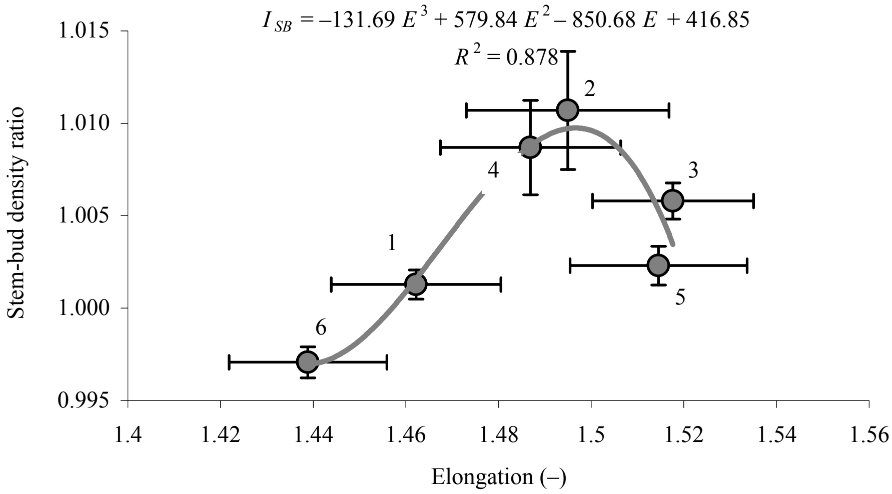

Fig. 3. Mean values of the stem-bud density ratio plotted against the mean values of the tuber elongation obtained for different regimes of cultivation. The bars denote the standard errors of the obtained data. The numbers at the experimental points denote the regimes of cultivation

Relation between tuber density and the shape parameters

Relation between tuber mean density and the shape parameters was analysed by multiple regression analysis under the following formula:

$$\rho = a_0 + a_1 m + a_2 SF + a_3 EL + a_4 F \qquad (5)$$

In addition to the shape parameters *SF*, *EL*, and *F*, the total tuber mass *m* as a measure of the tuber dimension was also taken into the analysis that is resulted in Tables 4 and 5. The results showed that degree of correlation is relatively low, with low values R^2 and relatively high p_{tot}. It indicated the existence of some causes controlling the density values that were not taken into the account in Eq. (5). Among them it seems to play the important role the individual conditions of the separate plants that were not under control; the specific role had to play plant diseases and the exact state of their maturity. The stage of a

Table 4. Regression parameters of the multilinear regression between the tuber mean density and its mass and shape factors – see Eq. (5). Grey cells correspond to the *p*-values less than 10% – see Table 5

Regime	a_0	a_1	a_2	a_3	a_4
1	1,088.2	0.0943	12.229	–5.497	–9.258
2	1,062.2	0.1037	5.988	3.032	13.708
3	1,124.8	0.1031	–32.211	8.818	–26.041
4	1,098.0	0.0373	–20.994	28.579	–36.356
5	1,192.1	0.0976	–52.232	–7.993	–52.522
6	1,136.5	0.0136	–13.373	–3.770	–32.552

Table 5. Probabilities $p(a_i)$ that the corresponding parameter in Eq. (5) is zero

Regime	$p(a_0)$	$p(a_1)$	$p(a_2)$	$p(a_3)$	$p(a_4)$	R^2	p_{tot}
1	< 0.0001	0.246	0.558	0.410	0.595	0.048	0.695
2	< 0.0001	0.323	0.818	0.766	0.606	0.028	0.854
3	< 0.0001	0.167	0.071	0.282	0.091	0.153	0.104
4	< 0.0001	0.626	0.265	0.0005	0.060	0.286	0.004
5	< 0.0001	0.457	0.071	0.542	0.042	0.129	0.172
6	< 0.0001	0.894	0.659	0.729	0.110	0.073	0.501

R^2 – square of the multiple regression coefficient, p_{tot} – total probability that the analysed data give the constant density value. p-values less than approximately 10% are marked by grey

tuber growth is related frequently to its dimension and shape (Van Es, Hartmans 1981). Our analysis gave not significant relation of tuber density to its tuber mass (Table 5) and only relatively low relation to its shape, that could be significant in some special cases (cultivation regime 4), indicating the potential role of different growth stages.

Tables 4 and 5 show that tuber density depended mainly on tuber thickness, for which the increase was connected with decreasing density. In two cultivation regimes the similar role was played by the shape factor. Only in one case the density increase was observed with increasing tuber elongation, but this dependence was very strong and it caused the higher total correlation coefficient in the regime 4; the regime with tubers probably harvested in different growth stages. Some relation between the tuber density and the shape parameters can be of nonlinear character. Fig. 3 shows nonlinear and nonmonotonic dependence of the stem-bud density ratio on the tuber elongation. The stem-bud density ratio increased with increasing elongation up to elongation values about 1.5 and than sharply decreased up to values close to 1.

CONCLUSIONS

Mean tuber densities of variety Agria cultivated at different conditions are approximately the same. The observed differences in the density standard deviations are caused by different participation of the tubers of lower density. The tuber density is relatively weak function of the tuber's dimension and shape. In this dependence the tuber flatness plays important role as well as the tuber elongation in some special cases. The main part of the tuber variability in density has another sources than that was under control in our experiments. The stem-bud density ratio is non-monotonic dependent on the tuber elongation with maximum value at elongation about 1.5. Statistical analysis indicated presence of the tuber groups of different shape character at least in some regimes of cultivation.

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Charakteristiky hustoty a tvaru hlíz brambor odrůdy Agria pěstovaných v různých podmínkách

ABSTRAKT: Brambory odrůdy Agria byly pěstovány s různým režimem hnojení a zavlažování. Rozměry a hustota hlíz byly studovány dva měsíce po sklizni s cílem najít souvislosti mezi hustotou hlíz a jejich tvarem. Byla také studována změna hustoty ve směru od pupku ke korunce určením dílčích částí hlíz: pupkové, střední a korunkové. Měření přinesla informace o relativně proměnlivých parametrech, které pouze slabě nebo zprostředkovaně závisejí na podmínkách pěstování.

Klíčová slova: brambory; hustota; pupek; korunka; režim pěstování; tvarový faktor; prodloužení; ploskost

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