ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LIX 1 Number 1, 2011

CONTOUR DETERMINATION AND SHAPE CHARACTERISTICS OF DIFFERENT VARIETIES OF POTATO TUBERS

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Received: August 12, 2010

Abstract

BUBENÍČKOVÁ, A., SIMEONOVOVÁ, J.: *Contour determination and shape characteristics of different varieties of potato tubers.* Acta univ. agric. et silvic. Mendel. Brun., 2011, LIX, No. 1, pp. 9–14

Precise determination of potato tubers' shape and variability existing among individual potato varieties is necessary e.g. for modeling of handling and transport processes. The procedures described in the work are used for determination and evaluation of potato tubers shape variability and proportional importance of four main principal components. Ten different potato varieties were analyzed (*Karin, Karlena, Krasa, Marilyn, Princess, Red Anna, Rosara, Sazava, Vendula,* and *Vera*) and elliptic Fourier descriptors employed for description of tubers shape. Following principal components were quantified: height to width ratio, position of the center of gravity, curvature, and degree of roundness. The scores of the resulting components were used in subsequent analysis as tuber shape characteristic. The first four principal components covered almost 100 % of the total variance in both, front and side-view shape and 97 % in top-view shape. Height to width ratio was evaluated as the determining parameter with contribution of 70.58–74.02 % of the total shape variation (front-view) for *Karin* and *Vendula* varieties respectively. The other principal components were significantly less affecting the overall variability. It was confirmed that described approach is precise and usable procedure for potato tubers shape analysis.

shape classification, potato tubers, image analysis, Fourier descriptors

Different potato varieties are characterized by various properties and attributes such as shape, size and/or volume. Shape evaluation and description is critical in numerous practical and processing applications such as sorting, storing, handling, and transport. Generally, concerning biological sciences, the shape evaluation can be used in morphometric-based evolution comparisons, taxonomy, comparative anatomy, identification and counting of cells, growth and shape modifications, microscopy, and other subjects. Concerning agriculture, image analysis was successfully employed for harvest control, seed counting and quality control, species identification, leaf classification, and fruit maturation analysis. Shape of the biological object including potato tubers often affects its mechanical properties. This problematic was deeply studied e.g. in Severa (2008a), Nedomová *et al.,* (2009a) or Nedomová *et al.,* (2009b).

The origin of computer vision is intimately intertwined with computer history, having been motivated by a wide spectrum of important applications. As far as the pictorial information is concerned, the particular issue of 2D shapes, i.e., shapes defined on the plane, is of paramount importance. An image formation often involves mapping objects from the three-dimensional (3D) space onto 2D structures (Costa and Cesar, 2009).

Various methods of describing the potato tuber shape have been suggested (Tabatabaeefar, 2002; Torppa *et al.,* 2006). The methods, in broader context, can involve the wide spectra of problems beginning at microstructure of the surface profiles (Severa and Buchar, 2000) and ending by processing and reducing of large amount of image analysis data (Bartoň *et al.,* 2010). One of the popular and precise methods is the approach based on the elliptic Fourier descriptors (EFDs) (Kuhl and Giardina, 1982).

The mathematical background underlying the Fourier analysis theory provides a large set of useful tools for shape analysis. For instance, it is possible to estimate several shape measures directly from the respective FDs. This method has been applied with success when evaluating different biological shapes (Iwata *et al.*, 2002; Yoshioka *et al.*, 2006; Havlíček *et al.*, 2008; Severa *et al.*, 2010 and other). The method offers mathematical description of entire shape through transforming coordinate information concerning the contour into Fourier coefficients. Principal component analysis of the coefficients can than extract the independent shape characteristics, and make it possible to analyze the shape quantitatively by using the component scores as ordinary quantitative characters (Rohlf and Archie, 1984).

This study is focused on evaluation of influence of potato variety on egg shape. It was tested if the analysis based on the EFDs is efficient and suitable for evaluating the potato variety as a factor influencing the tuber shape. The variability of tubers shape within 10 individual varieties was also calculated and analyzed.

MATERIAL AND METHODS

Potato tubers

The tubers were neither shaped nor altered in any way in order to keep their original character. The fresh tubers were used thus influencing of surface by longer storing was eliminated.

Ten varieties of potato tubers were analyzed: *Karin, Karlena, Krasa, Marilyn, Princess, Red Anna, Rosara, Sazava, Vendula,* and *Vera*.

Karin is a variety with prolonged, oval tubers, yellowish and smooth skin and yellow flesh. The variety was breeded in SATIVA Keřkov by cross-breedeing of *Rita* x *Hera*.

Karlena is an early or very early variety, with smaller tubers, lower crop and higher starch contain. The tubers are typically round-shaped with shallow eyes. The skin is yellowish, medium rough and the flesh is yellow.

Krasa is a very early variety, with larger tubers, medium crop and medium starch contain. The tubers are typically short and oval-shaped with shallow eyes. The skin is yellow, smooth or medium rough and the flesh is yellow.

Marilyn is a special variety for gourmet culinary use and sold to the final consumers under special brand mark. The product is produced by Medipo Agras H. B.

Princess is early variety, with larger tubers and higher crop. The tubers are typically short and oval-shaped. The skin is yellow, smooth or medium rough and the flesh is yellow.

Red Anna was breaded in Vesa Velhartice by cross-breading of *Rosella* x *Pamir*. The tubers are oval-shaped, the eyes are shallow, the skin reddish, smooth or slightly netted. The flesh is yellow. The eye is medium-sized and oval-shaped.

Rosara is a very early variety, with medium-sized tubers, medium crop and medium starch contain. The tubers are typically oval-shaped with shallow eyes. The skin is red, smooth or medium rough and the flesh is deep yellow.

Sazava is early to very early red-skinned variety. The content of starch in tubers is medium. Tuber shape is oval, larger, with shallow eyes, fairly smooth red skin and deep yellow flesh.

Vendula is early to semi-early market variety with high yield and prolonged oval tubers. The variety was breeded in Vesa Velhartice by cross-breedeing of *Rosella* x *Paola*.

Vera is a very early variety, with smaller-sized tubers, medium crop and medium starch contain. The tubers are typically short oval-shaped with shallow eyes. The skin is yellow, smooth or medium rough and the flesh is yellow.

1: *Transformation of the raw into binary image*

Tuber shape evaluation

The digital images of the tubers were acquired by digital camera Olympus SP-560UZ (Olympus, Japan). The images were taken along three main axes and hereinafter they are denoted as front view, side view and top view. The raw digital images with resolution of 180 dpi were consequently converted to full color (24-bit) bitmap format. This step was followed by converting the images into the gray scale. The gray scale images were converted to binary images in which the objects and background are represented as 1 (white) and 0 (black), respectively. Example of photos processing is given in Fig. 1.

Fourier descriptors

An original approach for obtaining the signal with use of Fourier descriptors, which describes the shape, was early presented by Zahn and Roskies (1972). The proposed following method: let Γ be a curve defined by the shape contour, which may be parametrically represented as $c(t) = (x(t), y(t))$, where t is the arc length parametrization and L is the curve perimeter. Let $\theta(t)$ be the angular direction of Γ, $\delta_0 = \theta(0)$ be the angular direction at the starting point $c(0)$, and $\Phi(t)$ be the cumulative angular function obtained from the accumulative integral of $\theta(t)$ from 0 to t. The creation of Fourier descriptors set invariant to translation, rotation and scaling requires the definition of a normalized function $\Phi_N(t)$. The complex signal $u(t)$ may be expanded in a complex Fourier series defined as

$$FD(s) = \frac{1}{L}\int_0^L u(t)e^{\frac{-j2\pi st}{L}}\,dt, \quad (1)$$

therefore

$$u(t) = \sum_{-\infty}^{\infty} FD(s)e^{\frac{-j2\pi st}{L}}. \quad (2)$$

In this work, following image and data processing was performed using freeware image analysis software Shape (Iwata and Ukai, 2002). Binary images with appropriate tresholds were used for creating closed contours of the tubers. The contours were described by a chain-code (Freeman, 1974). Each contour was represented as a sequence of x and y coordinates of ordered points that were measured counter-clockwise from an arbitrary starting point. Assuming that the contour between the $(i-1)$-th and i-th chaincoded points is linearly interpolated, and that the length of the contour from the starting point to the p-th point and the perimeter of the contour are denoted by the t_p and T, respectively, then the elliptic Fourier expansions of the coordinates on the contour are

$$x_p = A_0 + \sum_{n=1}^{\infty}\left(a_n\cos\frac{2n\pi t_p}{T} + b_n\sin\frac{2n\pi t_p}{T}\right), \quad (3)$$

and

$$y_p = C_0 + \sum_{n=1}^{\infty}\left(c_n\cos\frac{2n\pi t_p}{T} + d_n\sin\frac{2n\pi t_p}{T}\right). \quad (4)$$

Similar approach was applied for petal shape variation analysis (Yoshioka *et al.*, 2004) or chicken egg shape analysis (Havlíček *et al.*, 2008). The coefficients of elliptic Fourier descriptors that were normalized to avoid variations related to the size, rotation, and starting point of the contour traces, were then calculated from the chain-code through the procedure based on the ellipse of the first harmonic (Kuhl and Giardina, 1982). By this procedure, the tuber shape was approximated by the first 20 harmonics, which correspond to the 77 coefficients of normalized elliptic Fourier descriptors.

Principal components analysis based on a variance-covariance matrix of the coefficients was performed in order to summarize the information contained in the coefficients of the Fourier descriptors. The scores of the components were used in subsequent analysis as tuber shape characteristic. The variation in shape accounted for by each component was visualized using inverse Fourier transformation (Furuta *et al.*, 1995).

RESULTS AND DISCUSSION

Ten varieties were examined and ten pieces of tubers of each variety. The work is focused on validation of the method as a tool usable for shape variation description in case of potato tubers. Detailed quantification and precise statistical data and results processing would require much larger numbers of

I: *The dimensional parameters of experimental tubers*

Variety	Mean height (mm)	Mean width (mm)	Mean depth (mm)
Karin	66.04	51.94	43.26
s_x	6.58	5.94	5.38
Karlena	68.63	56.86	47.72
s_x	6.72	4.33	2.19
Krasa	67.16	58.94	49.48
	4.77	6.02	4.82
Marilyn	80.49	47.88	40.73
s_x	8.37	3.60	3.68
Princess	72.29	56.05	49.04
s_x	5.43	5.37	4.71
Red Anna	70.14	58.14	46.29
s_x	8.34	6.37	4.38
Rosara	83.75	52.25	41.62
s_x	7.16	5.36	3.45
Sazava	75.93	54.45	45.61
s_x	6.52	6.26	5.99
Vendula	73.44	52.78	44.54
s_x	6.29	5.04	5.08
Vera	82.74	62.79	53.23
s_x	5.07	4.53	4.24

tested tubers. The mean values of main dimensions of the tubers including standard deviation values are listed in Table I.

The data from image analysis were used for consequent comparative analyses of tubers' shape variability. The approach employed principal components analysis of elliptic Fourier descriptors. The mean tuber shape was drawn using the mean values of the standardized Fourier coefficients. The first four principal components provide a good summary of the data, same as in the case of e.g. hen eggs (Havlíček *et al.,* 2008), peaches (Severa, 2008b) or plant leafs (Furuta *et al.,* 1995). Four principal components accounted for 98.77–99.97% of the total variance in case of front view for *Red Anna* and *Karin* respectively, for 98.10–99.65% in case of side view for *Sazava* and *Marilyn* respectively, and for 96.21–96.90% in case of top view for *Sazava* and *Karlena* respectively. The example of computed values for front view is given in Table II. Component 1 corresponds to width to height ratio, component 2 to position of the center of gravity, component 3 to curvature, and component 4 to degree of roundness. The similar summarizations could be presented for both, side view and top view.

In case of all varieties, the width to height ratio was found to be the critical factor (principal component) influencing the general shape variation value. This conclusion is in accordance with finding reported by Tabatabaeefar (2002). The least proportion of overall variation was calculated in case of *Karin* variety (70.58 %), while the largest in case of *Vendula* (74.02 %). Other principal components, such as position of the center of gravity, curvature and/or roundness played a minor role in comparison with width to height ratio – see Table II.

Fourier descriptors method is one of the most popular shape representation approaches for vision and pattern recognition applications.

As documented above, this method represents accessible but powerful descriptive tool, which suits perfectly for evaluating of potato tuber shapes. The suitability of the method was proven, the differences among ten individual potato varieties were confirmed and the whole methodology can thus be used for further and more detailed potato tuber descriptions and possibly modeling of the operational or transport processes.

II: *Contributions of principal components – front-view*

Variety	Comp.	Proportion (%)	Cumulative (%)	Variety	Comp.	Proportion (%)	Cumulative (%)
Karin	1	70.58	70.58	**Karlena**	1	72.68	72.68
Karin	2	21.46	92.44	**Karlena**	2	21.12	93.80
Karin	3	5.49	97.53	**Karlena**	3	3.69	97.49
Karin	4	2.44	99.97	**Karlena**	4	1.42	98.91
Krasa	1	73.44	73.44	**Marilyn**	1	73.67	73.67
Krasa	2	20.83	94.27	**Marilyn**	2	20.32	93.99
Krasa	3	4.02	98.29	**Marilyn**	3	4.21	98.20
Krasa	4	1.01	99.30	**Marilyn**	4	1.07	99.27
Princess	1	71.18	71.18	**Red Anna**	1	72.41	72.41
Princess	2	19.88	91.06	**Red Anna**	2	20.09	92.50
Princess	3	6.13	97.19	**Red Anna**	3	4.31	96.81
Princess	4	2.48	99.67	**Red Anna**	4	1.96	98.77
Rosara	1	72.72	72.72	**Sazava**	1	72.09	72.09
Rosara	2	20.61	93.33	**Sazava**	2	21.14	93.23
Rosara	3	4.80	98.13	**Sazava**	3	3.90	97.13
Rosara	4	0.99	99.12	**Sazava**	4	2.69	99.82
Vendula	1	74.02	74.02	**Vera**	1	73.00	73.00
Vendula	2	19.86	93.88	**Vera**	2	22.11	95.11
Vendula	3	3.12	97.00	**Vera**	3	3.84	98.95
Vendula	4	2.32	99.32	**Vera**	4	0.64	99.59

SUMMARY

The work summarizes the results of quantification of shape variability of ten different varieties of potato tubers produced in the Czech Republic. The elliptic Fourier descriptors were chosen as a mathematical descriptive tool. The image analysis and following mathematical processing revealed that first principal component (which represents height to width ratio) is a very useful and applicable measure of the total shape variation. It represents 70.58–74.02% of the total shape variation (front-view) for *Karin* and *Vendula* varieties respectively. Not significantly different results were obtained for other two analyzed views – side-view and top-view. Four main principal components account for nearly 100% of the total variance in both, front and side-view shape and 97% in top-view shape. The common problem, which must be faced on when evaluating a small shape variations is solved by using elliptic Fourier descriptors and principal component analysis, because this procedure is highly accurate. Detection of rather small variations is difficult for humans, but the analyses based on the component scores can clearly detect significant variations among individual potato tubers. This method was validated as easily accessible but powerful and precise descriptive tool for evaluating of potato tubers shapes.

Acknowledgements

The research has been supported by the IGA 234/2101/SP2100321 and Grant Agency of the Czech Academy of Sciences under Contract No. IAA201990701.

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