QUANTIFICATION OF PEACH STONE SHAPE VARIABILITY BY MEANS OF IMAGE ANALYSIS

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ABSTRACT

Quantification and evaluation of peach (*Red Heaven*) stone shape variability was performed. Peach stones' shapes were described by several methods: measuring of main axes dimensions with consequent calculation of variation coefficients and expression of shape index; surface description by means of 3D scanning; and shape variation evaluation based on elliptic Fourier descriptors. The last approach enabled definition of influence of 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 stone shape characteristic. The variation in shape accounted for by each component was visualized using inverse Fourier transformation. The first four principal components provide a good summary of the data, accounting for almost 100 % of the total variance. Dominant importance and relevance of length to width ratio (with contribution of 44.24 % to the total variance) as a determining parameter of stone shape was quantitatively confirmed.

INTRODUCTION

The stone represents the hard endocarp and the enclosed seed of a drupe (such as peach). Following characteristics are usually considered when evaluating peach stones: size compared to fruit, shape, intensity of brown color, relief of surface, tendency of splitting, adherence to flesh, and degree of adherence to flesh. Stone size and stone shape can also be used as descriptive and cultivation characteristic of seedlings (Jakubowski and Lewandowska, 2004).
Peach shape appears stable and round whatever the level of domestication of the varieties, whereas stone shape is oval and more varying from one variety to another (Quilot *et al*., 2004).
Peach stone shape is not only important for fruit characterization but also eg. for designing the fruit stone removers and other equipment.

The aim of this paper is to compare different methods of peach stone shape description. Such characterization can be further used eg. for calculation of stone strength properties.

MATERIAL AND METHODS

Peach stones

For the purpose of experiment, a sample of 240 peach stones was collected. The peaches of *Red Heaven* variety (harvested in July 2008) have been used. Harvesting dates corresponded to different stages of peach maturation and have been selected as follows: 10.7.2008, 14.7.2008, 21.7.2008, and 28.7.2008. The peaches were obtained from the orchards of the Department of Postharwest technologies, Lednice, Mendel University of Agriculture and Forestry in Brno. Sixty peach stones have been processed each date. The stones have been excluded from the flesh and carefully cleaned by the scalpel. The stones had to be cleared of any residuals in order to get true and sharp contours and profiles. Such contours were necessary for further precise image analysis.

Stone geometry calculated from height (H) and width (W)

The height *H* of stone longitudinal axis and maximum width *W* were measured by digital micrometer SOMET (Germany). With regard to measurement accuracy and relevance, two decimal numbers were considered.

Stone geometry calculated from 3D scan

Precise description of the peach stone surface can be achieved by 3D scanning. Fig. 1a – front view, 1b – side view, and 1c – top view shows such digitalization. Optical digitizing system ATOS I from GOM mbH has been used. The system enables digitizing of any real object with known accuracy.

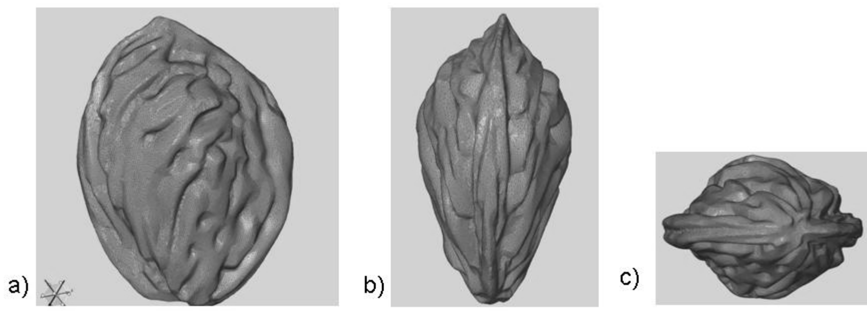
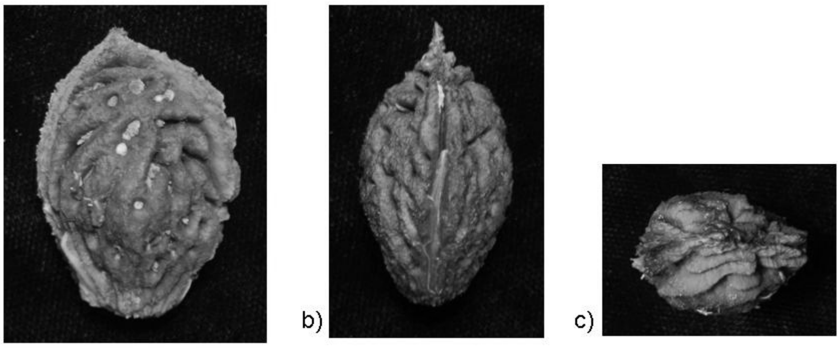


Figure 1

3D scan; a – front view, b – side view, c – top view

Measuring process is based on the principle of optical triangulation, photogrammetry and fringe projection. Projected fringe patterns are observed with two CCD cameras. 3D coordinates for individual points are calculated by the software. Automatic assemble of individual shots is accomplished through the reference points which are placed on the object. 3D coordinates of individual points are being captured during scanning process.

Evaluation of variation of stone shape based on image analyses using elliptic Fourier analyses. The stones have been photographed using a digital camera Olympus SP-560UZ (Olympus, Japan) and digital images with resolution of 180 dpi were acquired The raw images were converted to full color (24–bit) bitmap format. Example of captured photos is shown in Fig. 2.



a) b) c)

Figure 2
Raw digital photos; a – front view, b – side view, c – top view

This procedure was followed by converting the images to grey scale. The grey scale images were converted to binary images in which the objects and background are represented as 1 (white) and 0 (black), respectively. The image analysis software Shape (Iwata and Ukai, 2002) was used to perform all following steps. The closed contours of the stones were obtained through binary images with appropriate tresholds, and were described by a chain–code (Freeman, 1974). Namely, 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

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

And

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

The same method was used 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 peach stone shape was approximated by the first 20 harmonics, which correspond to the 77 coefficients of normalized elliptic Fourier descriptors.

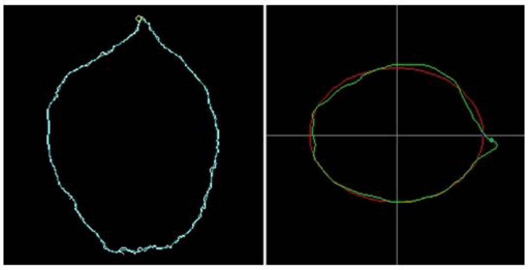


Figure 3
Selected stone's contour visualilization

To summarize the information contained in the coefficients of the Fourier descriptors, the principal components analysis based on a variance–covariance matrix of the coefficients was performed. The scores of the components were used in subsequent analysis as stone shape characteristic. The variation in shape accounted for by each component was visualized using inverse Fourier transformation (Rohlf and Archie, 1984; Furuta *et al.*, 1995). Example of such visualization is given in Fig. 3.

RESULTS AND DISCUSSION

Table 1 lists the basic statistics of performed measurements and calculations. Stone height, width and depth values represent the average of 50 individual measurements. V_x values represent the variation coefficient (normalized measure of dispersion of a probability distribution. It is defined as the ratio of the standard deviation to the mean value). One of the simplest instruments usable for description of stone shape is shape index (width/height ratio). Shape index (SI) is mainly used for description of egg shape (Sarica and Erensayin, 2004). Obviously it does not include the depth of the stone, but considering height and width as the main dimension, it has certain basic informative value.

Table 1: Measurements, variation coefficients and shape index of the peach stones

Harvesting date	Height (mm)	v_x	Width (mm)	v_x	Depth (mm)	v_x	Shape index	v_x
10.7.2008	40.1	0.08	26.5	0.05	18.17	0.11	0.67	0.11
14.7.2008	39.2	0.06	26.6	0.04	17.55	0.07	0.68	0.09
21.7.2008	39.9	0.07	26.4	0.05	18.05	0.09	0.66	0.10
28.7.2008	40.0	0.05	26.6	0.03	17.64	0.06	0.66	0.09

As it is evident from the listed values, none of the values has changed during monitored maturation period. It means, that stone formation was finished before this growth stage and can be further considered as constant. Generally, the least variable stone parameter was stone width with coefficient of variation ranging from 0.03 to 0.05. Highest variability was found for stone depth with v_x ranging from 0.06 to 0.11. Although there were no significant changes in size and shape, changes in strength characteristics can be expected due to varying amount of lignin (Nakano and Nakamura, 2002).
As it has been stated above, the most precise description of the stone surface can be achieved by means of 3D scanning. However, such procedure is rather expensive and technically demanding. Nevertheless, it offers accurate definition of surface spaces usable for further calculation of strength characteristics etc.
Comparative analyses of stones' shape variability was performed by image analysis, employing principal components analysis of elliptic Fourier descriptors. The mean stone shape was drawn using the mean values of the standardized Fourier coefficients. The first four principal components provide a good summary of the data, accounting for 100 % of the total variance (Table 2).

Table 2: Contributions of principal components

Component	Proportion (%)	Cumulative (%)	Indicator
1	44.24	44.24	height to width ratio
2	25.82	70.06	position of the center of gravity
3	16.74	86.80	curvature
4	13.20	100.00	degree of roundness

The contributions of the second, third and fourth principal components to the total variance were 25.82 % (position of the center of gravity), 16.74 % (curvature), and 13.20 % (degree of roundness), respectively (Table 2).

CONCLUSIONS

It was found that neither height, width nor depth of the peach stone has significantly changed during final periods of maturation. Calculated variation coefficients proven almost no influence of harvesting date on aforementioned variables.

Another effort was focused on quantification of stone shape variability by means of elliptic Fourier descriptors. Reconstructed shapes indicated that the first principal component (which represents height to width ratio) is very good measure of the total shape variation. It represents 44.24 % of the total shape variation. There are two major advantages of using elliptic Fourier descriptors and principal component analysis. Firstly, this approach can accurately detect small shape variations. Detection of rather small variations are difficult for humans, but the analyses based on the component scores can clearly detect significant variations among individual stones. Secondly, the analyses can evaluate the shapes of objects independently of size. This independence is a great advantage because human visual judgment of shape is often deceived and misled by size factors. Above mentioned method represents relatively simple but powerful interpretation tool which suits perfectly for evaluating of biological shapes.

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