Fractal Analysis of Apple Flesh Structure

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1. Introduction

Box-Counting method was used for evaluating of the fractal properties of the apple flesh texture. The method is often used to determine fractal box dimension of digitised images of fractal structures. Nežádal et al. (2001) and Buchníček et al. (2000) have implemented Box-Counting procedure in software called HarFA, which was developed on Institute of Physical and Applied Chemistry, Technical University of Brno in Czech Republic. HarFA analyses black&white images. Box-Counting method utilizes the covering fractal pattern with raster of boxes (squares) and than evaluating how many boxes N_{BW}, $N_{BBW} = N_B + N_{BW}$ or $N_{WBW} = N_W + N_{BW}$ of the raster are needed to cover fractal completely, where:

N_B - number of black squares,
N_W - number of white squares,
N_{BW} - number of black&white squares,
N_{BBW} - number of black&white and black squares,
N_{WBW} - number of black&white and white squares.

Repeating this measurement with different sizes of boxes $r = 1/\varepsilon$ will result into logarithmical function of box size r and number of boxes $N(r)$ needed to completely cover fractal. The slopes of the linear functions

$$\ln N_{BW}(r) = \ln(K_{BW}) + D_{BW} \ln(r), \quad (1)$$

$$\ln N_{BBW}(r) = \ln(K_{BBW}) + D_{BBW} \ln(r), \quad (2)$$

$$\ln N_{WBW}(r) = \ln(K_{WBW}) + D_{WBW} \ln(r), \quad (3)$$

give D_{BW}, D_{BBW} and D_{WBW} the fractal dimensions. D_{BW} characterises properties of border of fractal pattern. D_{BBW} characterises fractal pattern on the white background and D_{WBW} characterises fractal pattern on the black background.

2. Samples and storage properties

Measurement was realized for apples of variety Topaz. Experimental measurements were realized during of apple storage from 27th October 2003 to 2nd March 2004, i.e. in the start and the finish of the storage. Thirty values of fractal dimension were evaluated for each sample and variant of fertilization. Together 240 experimental values of the fractal dimension were realized for all variants. The new samples of apples were used for each measurement.

The storage was provided in the storage boxes at the temperature from 2°C to 3°C and 90% of the air moisture content. The measurement was realized for four variants A, B, C, K of the variety Topaz.

3. Experimental measurement

Apple samples were always cut on two half parts and the section of the depth 3-4 mm was cut from the middle part. Thirty area digital images were obtained from each sample section. The pores and the grains of the apple flesh represented a fractal object. Box Counting method was used for measurement of fractal dimension. Fractal dimension characterized influence of storage on the changing of the apple flesh structure. D_{BW}, D_{BBW} and D_{WBW} fractal dimensions were determined for surfaces of the area

samples scanned by video microscope combined with color digital CCD camera GKB CS-8606S with the array of size 768 × 576 pixels and trinocular microscope MI XSZ 107.

The frame grabber KAPA PLUS that provided the collaboration with PC digitised the images. The control software IMPOR'99 was used for a camera to provide a pre-processing of the snapshots. The software HarFA 4.9.3 was used for digital filtering of images and establishing of fractal dimension. The digitised samples were adjusted on the size 768 × 576 pixels with the resolution 38 pixels/cm. The magnification forty times was obtained. The real area of scanned surface was 3,4 × 3,4 mm for each digital image. The snapshot of the original apple flesh sample of variety Topaz, variant A is represented in the *Figure 1a*. The processing of the snapshot by intensity tresholding is shown in the *Figure 1b*. The fractal dimension of the flesh structure was evaluated from the equations (1,2,3).

4. Obtained results and discussion

Fractal dimensions D_{BW}, D_{BBW} and D_{WBW} were determined from 27 points equivalent 27 raster used on the each snapshot of the samples. The values 1.67963, 1.90499, 1.82381 from the equations shown below represents the experimental values of the fractal dimensions D_{BW}, D_{BBW} and D_{WBW} of the flesh structure of the variety Topaz, variant A shown in the *Figure 1* at the beginning of storage. R is a correlation coefficient. The values in the brackets are standard deviations of the slope and intercept in the regression model.

$\ln N_{BW} = 1.67963 \ln(r) (\pm 0.03729) + 11.74606 (\pm 0.11915)$; $R = 0.98831$

$\ln N_{BBW} = 1.90499 \ln(r) (\pm 0.00846) + 12.62747 (\pm 0.02651)$; $R = 0.99951$

$\ln N_{WBW} = 1.82381 \ln(r) (\pm 0.01484) + 12.31104 (\pm 0.04651)$; $R = 0.99835$

The same procedure was realized for all 240 snapshots of the samples and the arithmetical averages of the fractal dimensions were calculated. Each average was calculated from thirty values. The 720 experimental values of fractal dimensions were used together.

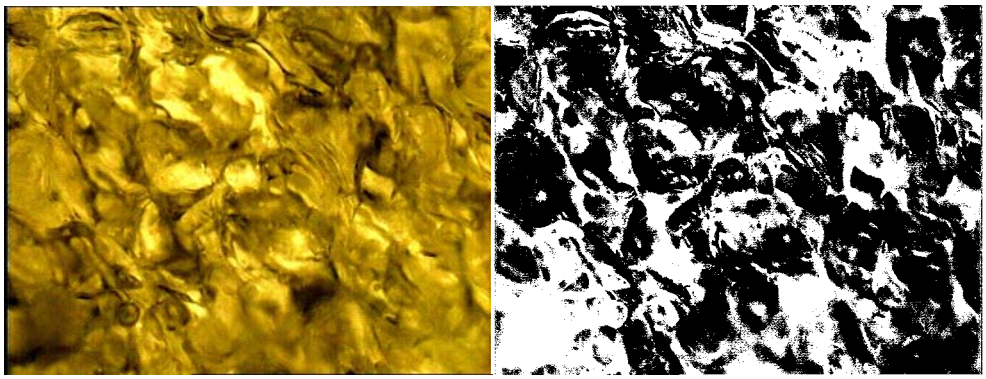

Figure 1 Original snapshot of apple flesh and the processing of the snapshot by HarFA's intensity tresholding. Variety Topaz, variant A at the beginning of storage (40 times magnification)

The graphical representation of the regression equations for one evaluation of the trinity of the fractal dimensions of the apple flesh of variety Topaz, variant A at the beginning of storage (from *Figure 1*) is shown in the *Figure 2*. D_{BW} characterized the properties of the border of black and white colour, i.e. the border of pores and grains of the fractal apple flesh. Its value was the smallest from the trinity of dimensions. D_{BBW} characterized the properties of the grains of the apple flesh structure. Its values were the highest from all. It means that the grains mesh the most part of the apple flesh structure. D_{WBW} characterizes the properties of the pores of the apple flesh and its values were between D_{BW} and D_{BBW}.

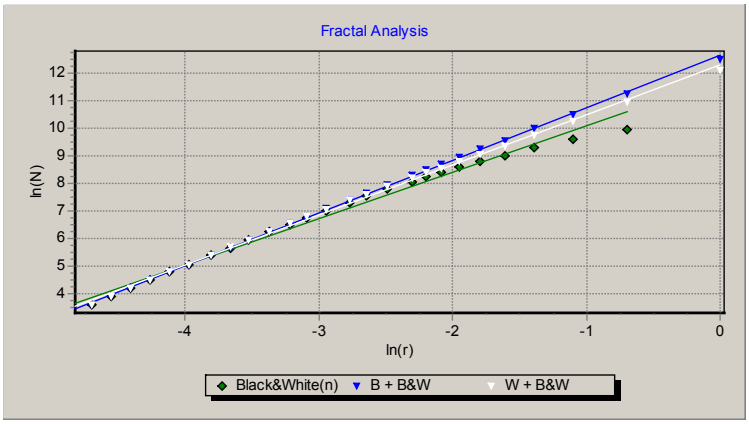

Figure 2 Determination of fractal dimensions D_{BW}, D_{BBW} and D_{WBW} by Box Counting method (software HarFA). Variety Topaz, variant A at the beginning of storage.

The study of influence of long period storage on the fractal dimension and influence of variants of fertilization in dependency on the time on the fractal dimension was also realized by statistical methods. Analysis of variance was used after data test of normality (Shapiro-Wilks'W test) and data test of variance correspondence (F-test). Statistical calculations were realized by software Statistica ver. 6.0. Analysis of variance of fractal dimension D_{BBW} of variety Topaz for factor variant of fertilization and time of storages is shown in the *Figure 3*.

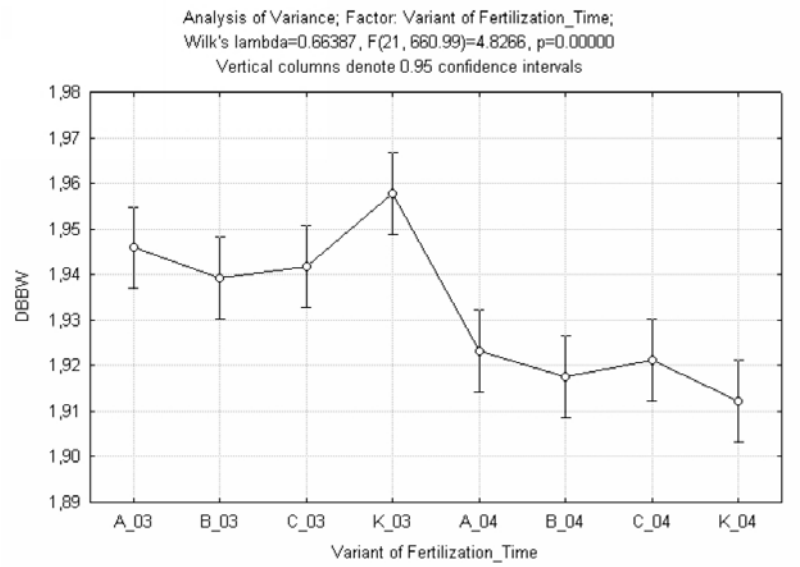

Figure 3 Analysis of variance of fractal dimension D_{BBW} of variety Topaz for factor variant of fertilization and time of storage. F is F-statistic of the F distribution and p is probability level.

5. Conclusion

The method of fractal analysis of the apples of the variety Topaz was used at the study of the apple flesh structure which is changing in the period of the long term storage in standard conditions. The fractal dimensions of the apple flesh express the degradation of apple structure caused by changing of representation of the pores and grains during the period of storage. The flesh structure transforms during long term storage in consequence of maturing and the chemical processes, which are passing inside.

The effect of the variant of fertilization and the time of storage on the fractal dimensions D_{BW}, D_{BBW} and D_{WBW} was proved by method of analysis of variance. D_{BBW} dimensions, which characterised the properties of the grains of the apple flesh structure decreased in dependency of time of storage. D_{WBW}

dimensions, which characterises the properties of the pores of the apple flesh structure increased in dependency of the time of storage.

Acknowledgement

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6. Literature

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