Evaluation of long term storage of apples by means of fractal analysis

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ABSTRACT: Realization of long-term apple storage requires the most detailed information about the flesh structure and texture, whose quality is contributing by responsible way to the whole quality of the evaluated fruits. The fractal analysis that the fractal dimension of the flesh structure determination is enabling was used. Structure degradation of four apples variants of the variety Idared was evaluated by fractal dimension during long-term storage in standard conditions. The influence of the storage on the fractal dimension was investigated by means of regression dependencies. The dependences express a decrease of the fractal dimension value in the relation to the increasing storage period. The influence of long term storage and influence of the variants of the fertilization on the fractal dimension was confirmed by means of analysis of variance. Connectivity between fractal dimension and descriptors of quality of the apple flesh structure was determined with utilization of the sensoric analysis. Fractal dimension expresses the structural and textural properties of the apple flesh.

Keywords: storage; fractal; apples; flesh; structure

The methods of senzoric analysis which evaluate a quality of apples in the period of long-term storage by means of senzoric analysis are often used to determination of texture properties of fruits by collection of descriptors (HORČIN, FINDOVÁ 2000). The physical methods as non-contact resonance Doppler analysis (BROZMAN, KUBÍK 2000) are used for determination of mechanical properties of fruits, especially determination of resonance frequency and modulus of elasticity. The measurement of electrical and thermal conductivity of fruits enables the evaluation of storage quality (HLAVÁČOVÁ 2002). Determination of structural and textural properties of apple flesh can be also realized by means of method of fractal analysis. That method as unconventional method in physics and agriculture enables to determine non-integer parameter – fractal dimension, which evaluates the degradation of the flesh structure in dependency on the period of storage. Fractal analysis was used especially for the evaluation of structural properties of soil. OLESCHKO et al. (1998) estimated the fractal dimension of the soil solid and pore systems along the lines and also across areas as useful parameter for monitoring the impact of tillage on physical properties of soil and also for evaluation of soil compaction degree. The founder of fractal geometry was B.B. Mandelbrot (LESORT 1986). FEDER (1988) considerably developed the fractal analysis. The first Mandelbrot's works were from the field of geophysics. They were treated by the characteristics of seacoast relief. Mandelbrot showed that the curves observed at the different scales are able to refer one to another in form of power low. The exponent was denominating the fractal dimension. Afteward Mandelbrot applied the concept of fractal geometry on the areas as price diversification, frequency of words in the books, embranchement of respiration tubes, rivers, and tree branches (MANDELBROT 1982).

MATERIAL AND METHODS

Fractal analysis

The term fractal comes from Latin word *fractus* and its sense is broken or fractional. The fractals are geometric and mathematical objects which Hausdorff-Besicovitch's dimension D_{HB} is sharply greater than topological dimension D_T. Topological dimension is usual term of dimension, which allocates the dimension one to the line, dimension two to the surface and dimension three to the space. Hausdorff-Besicovitch's dimension is called fractal dimension D_F for fractals objects and than $D_F = D_{HB}$. Hausdorff-Besicovitch's dimension is unique positive number, whose calculation formula of Hausdorff measure do not give neither zero nor infinity but some "reasonable" number. The term measure is used for generalization of the concepts of lenght, surface and volume. The measure is a formula, which allocates a non-negative number to subset of Euclidean space expressing its size thus the measure. The Hausdorff measure is given by equation (FEDER 1988)

$$M_d = \sum\Gamma(d)R^d = \Gamma(d)N(R)R^d \xrightarrow[R \to 0]{} \begin{cases} 0, & d > D_{HB} \\ \infty, & d < D_{HB} \end{cases} \quad (1)$$

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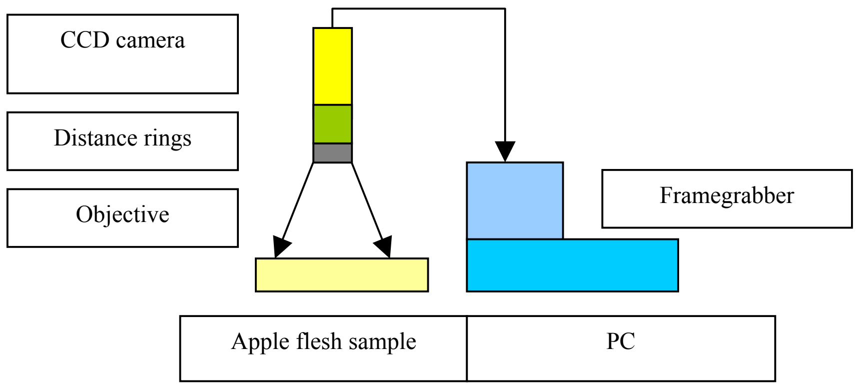

Fig. 1. Recording equipment

where: d – the measure dimension M_d,
R – a segment needed for covering of measured set,
$N(R)$ – a number of segments of size R,
$\Gamma(d)$ – a geometrical factor.

It is equal one for line, square and cube. The most important property of the fractals is selfsimilarity, invariance toward variance of scale. The base equation for determination of fractal dimension is possible to derive from equation (1),

$$\ln N(R) = \ln A - D \ln R \quad (2)$$

where: the fractal dimension was determined as a slope of equation (1),
A – a constant.

Samples and storage properties

Measurement was realized for apples of variety Idared. The samples came from Slovenský vodohospodársky podnik, s. p., o. z. Hydromeliorácie Bratislava, from the locality Most near Bratislava. Experimental measurements were realized during the apple storage from 23. 2. 2002 to 27. 6. 2002 approximately in the months intervals. The four measurements in dependency on the duration of storage were provided for each variant. Thirty values of fractal dimension were evaluated for each sample. Together 120 experimental values of the fractal dimension for each of four variants and together 480 experimental values of fractal dimension for all variants. The new samples of apples were used for each measurement.

The storage was provided in 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 Idared. The variants differed by the method of the fertilization and irrigation (Table 1). Fertigation irrigation was realized as dropping irrigation where the liquid contained the nutritive substances.

Experimental measurement

Apple samples were always cut in 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. The "box counting" method was used for measurement of fractal dimension (OLESCHKO et al. 1998). The capacite fractal dimension was determined. Fractal dimension characterized influence of storage on the changing of the apple flesh structure. Fractal dimension was determined for surfaces of the area samples scanned by black and white CCD camera SONY CB-2801 with the array of size 768 × 576 pixels and the images were digitized by the framegrabber KAPA PLUS which provided the collaboration with PC. The control software IMPOR'99 was used for a camera to provide a preprocessing of the snapshots. The software KARL2 was used for estab-

Table 1. Fertilization dosage and methods of irrigation and fertilization for the Idared variety

Variant	Fertilization dosage (kg/ha)			Method of irrigation and fertilization
	N	P_2O_2	K_2	
A	80	80	125	fertigation irrigation, liquid fertilization
B	120	120	125	fertigation irrigation, liquid fertilization
C	80	80	125	fertigation irrigation, solid manure
K	80	80	125	rainfall, solid manure

Table 2. The size of the square side R of the raster

R (pixel)	2	4	6	8	10	12	14	16
R (mm)	0.013	0.026	0.039	0.052	0.065	0.078	0.091	0.104

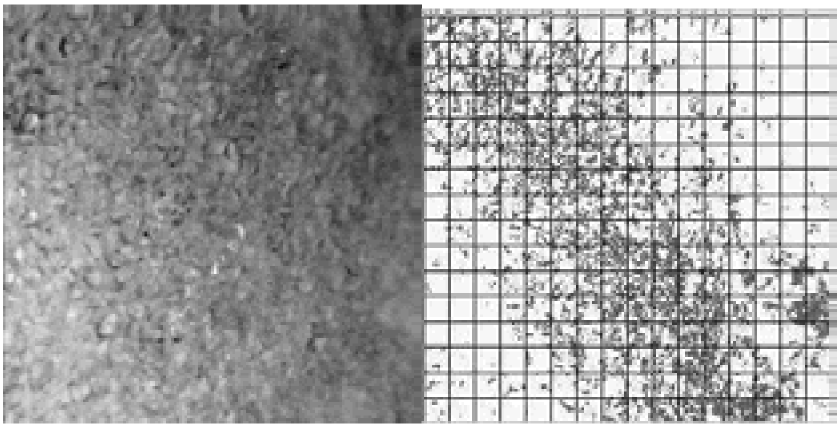

Fig. 2. Digital snapshot of the apple flesh structure of the variety Idared and their representation after graphic filtration and application of raster of the side size R = 32 pixels

lishing of fractal dimension. The block diagram of the recording equipment is shown in Fig. 1. The digitized samples were adjusted to the 512 × 512 pixels size with the resolution 38 pixels/cm. The forty times magnification was obtained by means of distance rings. The real area of scanned surface was 3.4 × 3.4 mm for each digital image. The adaptation was needed for using of the software KARL2 to process the digitized snapshots. The good contrast between black and white colour was achieved by graphic filtering on the digitized sample snapshots. The selected grey tone represented the pores and the supplementary grey tone the grain of the apple flesh. The program KARL2 was sensitive to the selective choosen grey colour from 256 grey tones. The pores and the grains of apple flesh were modeled by the squares of the side R. The digitized samples were covered by raster of the side size square R (pixel). The eight rasters were used for each sample. The raster was changed through different sizes (Table 2) and the occupation of the squares N(R) was always determined. Thirty digital snapshots of the sample structure were obtained from each apple sample. The number of pores was always determined and so the surface porosity of the sample and the fractal dimension were established. The snapshots of the apple flesh sample are represented in Fig. 2.

The inhomogeneous ligting of the scanned structure caused that the pores and grains in the upper right corner of images (too dark) and in the left low corner of the images (too clear) did not scan correctly. To avoid of the error in the number of pores only diagonal part of images was deliberated. The fractal dimension of the flesh structure was evaluated from the equation (2).

Table 3. Regression equations of the fractal dimension D on the period of storage X and their correlation coefficients

Variant	Regression equation	Correlation coefficient
A	$D = 1.7608\ X^{-0.0236}$	0.989
B	$D = 1.6861 - 0.0013\ X$	0.986
C	$D = 1.7617\ X^{-0.0284}$	0.988
K	$D = 1.6466 - 0.0009\ X$	0.893

RESULTS AND DISCUSSION

The graphical representation of the regression equation for one evaluation of the fractal dimension of the apple flesh structure for digital image in Fig. 2 is in Fig. 3. The equation was always determined from eight points equivalent eight rasters used on the sample. The value of the fractal dimension was 1.5774 as follows from the regression equation $\ln N = 11.1882 - 1.5774 \ln R$. Thirty regression equations were established for the resultant value of the fractal dimension for one time point in the duration of long term storage. Together 120 experimental values of the fractal dimension for each of four variants and together 480 experimental values of fractal dimension for all variants A, B, C, K were evaluated.

The dependences of the fractal dimension of variants A, B, C, K on the period of storage are presented in Fig. 4. The corresponding values are the arithmetical averages calculated always from thirty measured values. The corresponding regression equations and correlation coefficients are presented in Table 3.

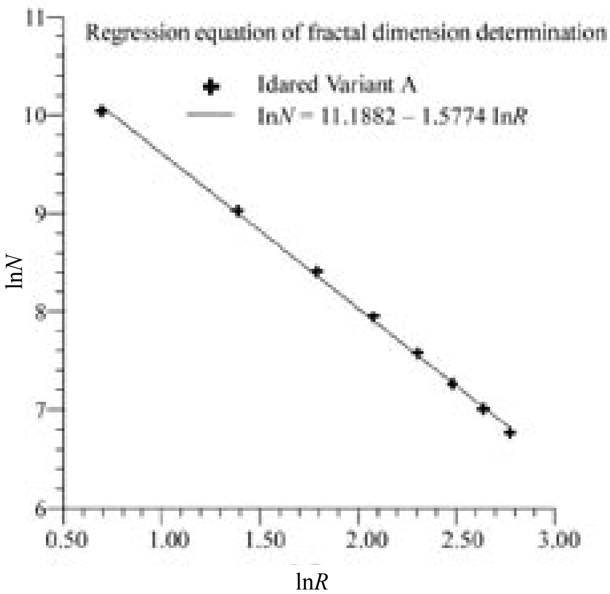

Fig. 3. Determination of fractal dimension as the slope of the line by method of regression

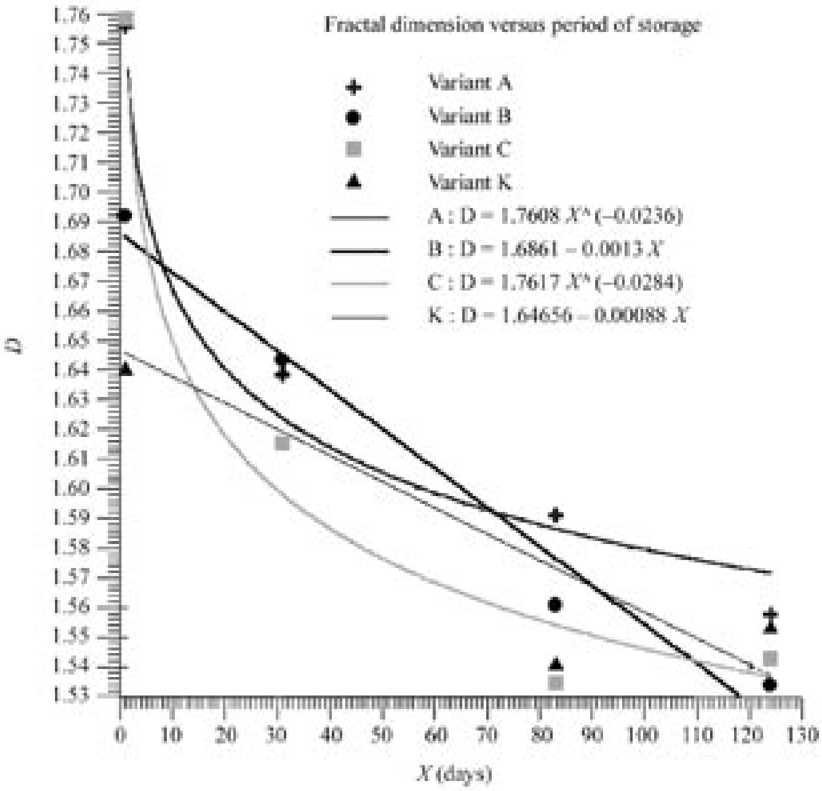

Fig. 4. Dependences of the fractal dimension D of the apple flesh structure of the variety Idared on the period of long term storage X

The fractal dependences characterize the fractal status of the apple flesh structure. They represent the decreasing trend of fractal dimension in the relation to the period of storage. The different type of the regression functions is probably caused by the great anisotropy of the apple flesh structure in the particular samples since new apple samples were used at each following measurement.

The study of influence of long period storage on the fractal dimension and influence of variants of fertilization in dependence on the time on the fractal dimension was also realized by statistical methods. Analysis of va-

Table 4. Analysis of variance for influence of the factor the time of storage on fractal dimension

Source of variation	Sum of squares	d.f.	Mean square	F-ratio	Sig. level
Between groups	2.123105	3	0.1662228	125.567	0.0000
Within groups	2.682754	476	0.0049839		
Total	4.805859	479			

Table 5. Multiple range analysis for fractal dimension D by time of storage. Method is 95% Scheffe test. *denotes a statistically significant difference

Level	Count	LS mean	Homogeneous groups
02junid	120	1.5468558	X
02majid	120	1.5568725	X
02marid	120	1.6342333	X
02febrid	120	1.7115792	X
Contrast		difference	limits
02febrid – 02marid		0.07735	0.02673*
02febrid – 02majid		0.15471	0.02673*
02febrid – 02junid		0.16472	0.02673*
02marid – 02majid		0.07736	0.02673*
02marid – 02junid		0.08738	0.02673*
02majid – 02junid		0.01002	0.02673

riance and Scheffe test were used after data test of normality (χ^2 test) and data test of variance correspodence (F-test).

The time of storage had determining influence on the variability of fractal dimension (Table 4). The average variability between groups caused by factor time of storage was larger (0.1662228) than the variability within groups comes from different sources (0.0049839). The critical value of F-statistics with degrees of freedom 3 and 476 on the significant level 0.05 (95% confidence level) is 2.62739. We accept the alternate hypothesis, that the average values of the fractal dimensions are significantly different, because of computed statistic (F-ratio) has bigger value (125.567). The critical value of F-statistics and all statistical calculations were realized by Statgraphics ver. 5.0 software. Then we used the method of multiple range analysis by means of Scheffe test (Table 5).

Identification of the labels used in Table 5 is described in Table 6. This method enabled to find out the significant differences between the average values of the fractal dimensions by means of multirange comparison of their differences. From Table 5 followed that the average values of fractal dimensions are different on the basis of statistically significant difference caused by factor time of storage with 95% probability. In the column Homogeneous groups the letters X placed under them denoted which fractal dimensions we are able to arrange in the same group, because the differences between them are not significant. The first homogeneous group is created by the average dimensions from June and May, the second group the average dimension from March and the third group the fractal dimension from February. It follows that the fractal dimension of the apple flesh structure changed from February to May, but did not change from May to June. We can see the differences better in the column contrast. The significant differences are denoted by*. The average values of the fractal dimensions had descending trend (from February to May) what is the good correspodence with data in Fig. 4. There was not observed the significant difference in the fractal dimension (also in the flesh structure) from May to June. Box and Whisker plot for factor time of storage of variety Idared apples is also presented in Fig 5. The boxes represent the low and top quartiles. The horizontal line placed inside the box denotes the median. The ends of the vertical rays denote the minimal and maximal values. The rays are maximally 1.5 times longer than box. The values which are more longer are denoted as individual points. The values situated 3 times longer than length of the box are denoted as +.

The influence of the factor of the variant of fertilization (A, B, C, K) on fractal dimension in the relation to the time of storage was also evaluated. The variant of fertilization had significant influence on the variability of fractal dimensions (Table 7). The average variability between groups caused by factor variant of fertilization was 0.1662228 and the variability within groups coming from different sources was 0.0049839. There is the same result as for the factor time of storage. The critical value of F-statistics with degrees of freedom 15 and 464 on the significant level 0.05 is 1.6892. We accept again the alternate hypothesis, that the average values of the fractal dimensions are significantly different, because the computed statistic (F-ratio) has bigger value (33.352).

Then we used the method of multiple range analysis by means of Scheffe test (Table 8). Identification of the labels used in Table 8 is described in Table 6 again. From Table 8 followed that the average values of fractal dimensions are different on the basis of statistically significant difference caused by factor variant of fertilization, with 95% probability. In the column Homogeneous groups the letters X placed under them denote four homogeneous groups of average values of fractal dimensions. We can see rather the influence of period of storage than influence of fertilization, but average values of fractal dimensions for variants of fertilization B, C, K for May and June are different from variants A, K, B for February and March and also for variants A, C from February (see the Homogeneous groups in Table 8). In detail we evaluated the contrasts caused by factor fertilization. The significant differences caused by factor fertilization are denoted by*. From the column Contrast in Table 8 followed that fractal dimensions of variant A were significantly changed from February to

Table 6. Identification of the labels used in the analysis of variance

Mark	Date of measurement	Mark	Variant	Variety
02febrid	23th February 2002	Aidfeb	A	Idared
02marid	26th March 2002	Bidmar	B	Idared
02majid	15th May 2002	Cidmaj	C	Idared
02junid	27th June 2002	Kidjun	K	Idared

Table 7. Analysis of variance for influence of the factor of the variant of fertilization on fractal dimension

Source of variation	Sum of squares	d.f.	Mean square	F-ratio	Sig. level
Between groups	2.493342	15	0.1662228	33.352	0.0000
Within groups	2.312517	464	0.0049839		
Total	4.805859	479			

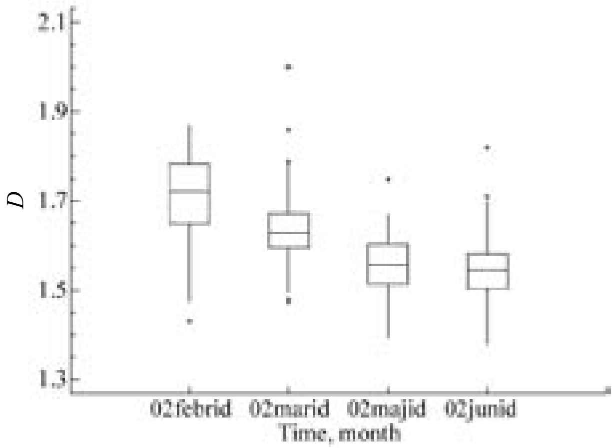

Fig. 5. Box and Whisker plot for factor time of storage of variety Idared apples

March. The significant change was not observed from March to May and from May to June. But differences from February to May and to June were statistically significant. The fractal dimensions influenced by variant B of the factor of fertilization were not significantly different from February to March from March to May and from May to June. The significant change was observed only from February to May. The significant difference of the fractal dimension from February to June was the same change as the change from February to May. The influence of variant C of the factor of fertilization was statistically significant from February to March. Other significant changes of the fractal dimensions denoted by* followed from that change of the fractal dimension. The statistically significant changes influenced by variant K of factor of fertilization were observed between February and May, but that change of the fractal dimension was created from March to May. The significant change between February and June was not observed. In comparison with data in Fig. 4 we could confirm the significant differences between fractal dimensions from February to June for variant A, B, C of factor of fertilization. Variant K of fertilization caused significant differences of fractal dimensions only from February to May.

Box and Whisker plot for factor of variant of fertilization of Idared apple variety is also presented in the Fig. 6. The boxes represent the low and top quartiles. The horizontal line placed inside the box denotes median. The ends of vertical rays denote the minimal and maximal values. The rays are maximally 1.5 times longer than box. The values which are more longer are denoted as individual points. The values situated 3 times longer than length of the box are denoted as +.

We are interested in relation of fractal dimension to the polarity descriptor intensity of apple flesh structure and texture during the period of storage also. The polarity descriptors are the quantities which represent the structure and texture state of apple flesh. The descriptors create the polarity couples which represent the quality of the apple flesh. The couples of the polarity descriptors are shown in Table 9. The intensity of polarity descriptors was in the range from 0 to 6, where the values near to 0 represented negative properties of the flesh structure and texture and the values near to 6 represented positive properties of the flesh structure and texture.

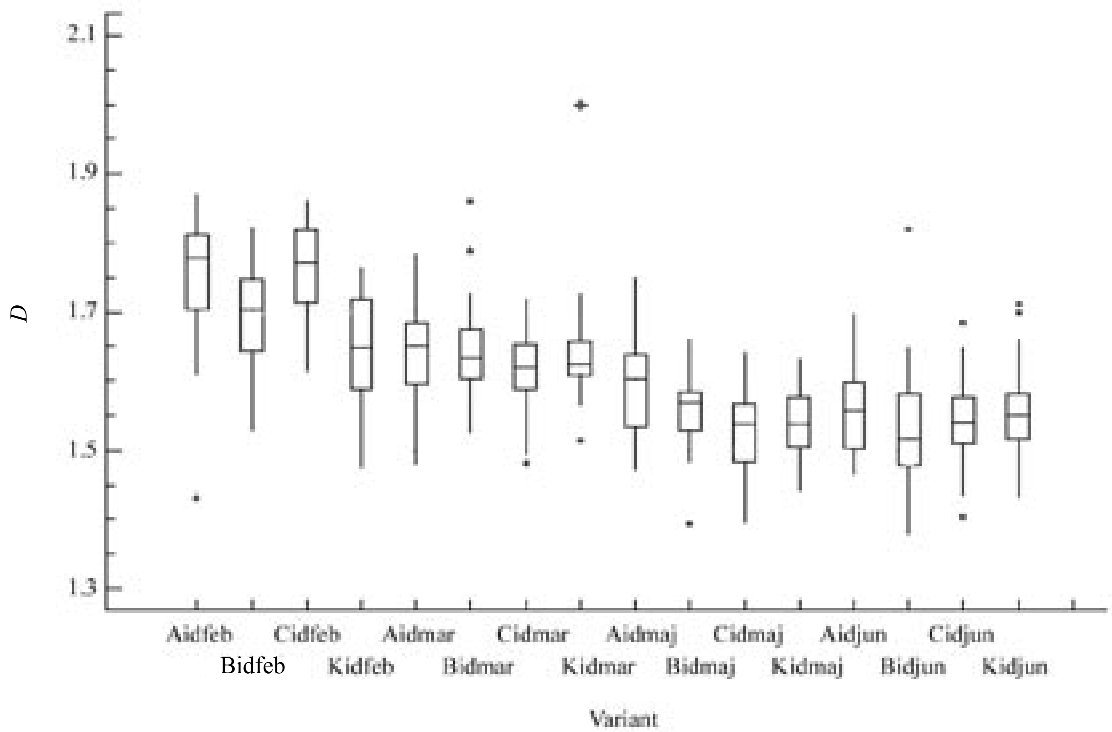

Fig. 6. Box and Whisker plot for factor variant of fertilization of variety Idared apple

Table 8. Multiple range analysis for fractal dimension *D* by variant of fertilization A, B, C, K. Method is 95% Scheffe test. *denotes a statistically significant difference

Level	Count	LS mean	Homogeneous groups
Bidjun	30	1.5337833	X
Cidmaj	30	1.5346300	X
Kidmaj	30	1.5411467	X
Cidjun	30	1.5427167	X
Kidjun	30	1.5534033	XX
Aidjun	30	1.5575200	XX
Bidmaj	30	1.5606833	XX
Aidmaj	30	1.5910300	XX
Cidmar	30	1.6151800	XXX
Aidmar	30	1.6383900	XX
Kidmar	30	1.6401367	XX
Kidfeb	30	1.6405467	XX
Bidmar	30	1.6432267	XX
Bidfeb	30	1.6916900	XX
Aidfeb	30	1.7558733	X
Cidfeb	30	1.7582067	X
contrast		difference	limits
Aidfeb – Aidmar		0.11748	0.09175*
Aidfeb – Aidmaj		0.16484	0.09175*
Aidfeb – Aidjun		0.19835	0.09175*
Aidmar – Aidmaj		0.04736	0.09175
Aidmar – Aidjun		0.08087	0.09175
Aidmaj – Aidjun		0.03351	0.09175
Bidfeb – Bidmar		0.04846	0.09175
Bidfeb – Bidmaj		0.13101	0.09175*
Bidfeb – Bidjun		0.15791	0.09175*
Bidmar – Bidmaj		0.08254	0.09175
Bidmar – Bidjun		0.10944	0.09175*
Bidmaj – Bidjun		0.02690	0.09175
Cidfeb – Cidmar		0.14303	0.09175*
Cidfeb – Cidmaj		0.22358	0.09175*
Cidfeb – Cidjun		0.21549	0.09175*
Cidmar – Cidmaj		0.08055	0.09175
Cidmar –Cidjun		0.07246	0.09175
Cidmaj – Cidjun		–0.00809	0.09175
Kidfeb – Kidmar		0.00041	0.09175
Kidfeb – Kidmaj		0.09940	0.09175*
Kidfeb – Kidjun		0.08714	0.09175
Kidmar – Kidmaj		0.09899	0.09175*
Kidmar – Kidjun		0.08673	0.09175
Kidmaj – Kidjun		–0.01226	0.09175

The intensity of polarity descriptors was always determined by a team of trained workers on the base of their subjective feeling. This method is known as sensoric analysis. The team was examined by statistical methods and the workers who did not achieve the asked appreciation were eliminated.

We realized the evaluation of apple flesh structure and texture during the long period storage (from February to June) for the variety Idared and variant fertilization A. The dependency of fractal dimension on polarity descriptors intensity is shown in Fig. 7. The dependencies were created only from four points (four months). They express decreasing dependency of the fractal dimension *D* on polarity descriptor intensity for all descriptors. When the fractal dimension is decreased the positive values of descriptor intensity

Table 9. The polarity descriptors of apple flesh structure and texture and intensity of their polar components

	Intensity of polarity descriptors						
Descriptors (–)	0–1	1–2	2–3	3–4	4–5	5–6	Descriptors (+)
1 withering of fruit	negative		neutral		positive		1 freshness of fruit
2 thick skin							2 thin skin
3 inadequate hardness							3 adequate hardness
4 abnormal juiciness							4 optimal juiciness
5 firmness of the flesh							5 fragility of the flesh
6 tenacity to chew							6 malleability to chew
7 mealiness of the flesh							7 fixing of the flesh
8 glassiness of the flesh							8 unglassiness of the flesh

Table 10. Regression equations of the fractal dimension *D* on the descriptor intensity I and their correlation coefficients. Polarity descriptor couples:1 – withering of fruit, freshness of fruit, 2 – thick skin, thin skin, 3 – inadequate hardness of the flesh, adequate hardness of the flesh, 4 – abnormal juiciness, optimal juiciness, 5 – firmness of the flesh, fragility of the flesh, 6 – tenacity to chew, malleability to chew, 7 – mealiness of the flesh, fixing of the flesh, 8 – glassiness of the flesh, unglassiness of the flesh

Descriptor	Regression equation	Correlation coefficient
1	$D = 3.0765 - 0.2846\ I$	0.786
2	$D = 3.3217 - 0.3967\ I$	0.934
3	$D = 2.7708 - 0.2359\ I$	0.651
4	$D = 2.1674 - 0.1135\ I$	0.901
5	$D = 2.6000 - 0.2085\ I$	0.601
6	$D = 2.6350 - 0.1950\ I$	0.974
7	$D = 2.6572 - 0.2018\ I$	0.994
8	$D = 2.1450 - 0.0870\ I$	0.107

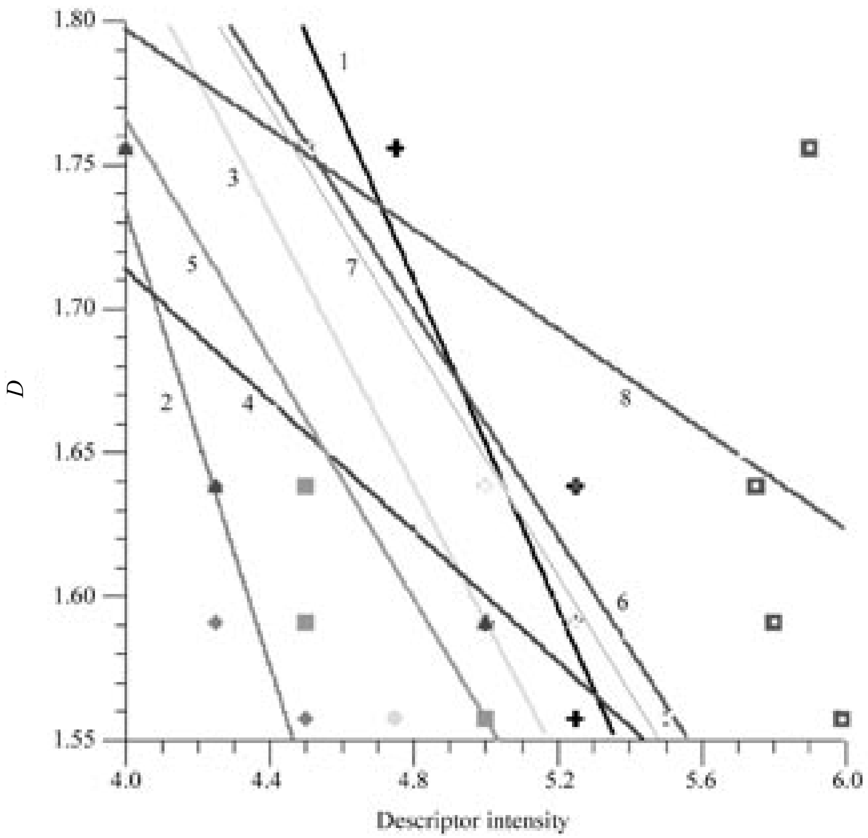

Fig. 7. Fractal dimension *D* dependency on polarity descriptor intensity for apple of variety Idared and A variant of fertilization from February to June. Polarity descriptor couples:1 – withering of fruit, freshness of fruit, 2 – thick skin, thin skin, 3 – inadequate hardness of the flesh, adequate hardness of the flesh, 4 – abnormal juiciness, optimal juiciness, 5 – firmness of the flesh, fragility of the flesh, 6 – tenacity to chew, malleability to chew, 7 – mealiness of the flesh, fixing of the flesh, 8 – glassiness of the flesh, unglassiness of the flesh

are increased. The regression function dependences of fractal dimension on descriptor intensity are represented in Table 10.

CONCLUSION

The method of fractal analysis of the apples of the variety Idared 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 dependences of the fractal dimension on the period of storage have the decreasing trend. That effect can be induced by variation of the apple flesh structure. The dependences would be able to be linear and power functions. The heterogeneousness of the dependences is caused by the great anisotropy of the apple flesh among individual variants A, B, C, K and actually among individual apple fruits. The great influence has also different size of the apple fruits at the same variant for each next measurement.

The obtained data were tested by means of analysis of variance and the changes of the fractal dimension influenced by long period storage were confirmed. We succeed to find out the changes in the apple flesh structure in detail from month to month. The influence of variant of fertilization on fractal dimension was also confirmed. We determined also the connectivity of the fractal dimension and descriptors of quality. The obtained functions express decreasing dependency of the fractal dimension D on polarity descriptor intensity for all descriptors.

The achieved results show possibilities to evaluate continuously the quality of the structural properties of apples in the period of long term storage by one parameter – fractal dimension.

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Hodnotenie dlhodobého skladovania jabĺk pomocou fraktálnej analýzy

ABSTRAKT: Zabezpečenie dlhodobého skladovania jabĺk vyžaduje čo najpodrobnejšie poznatky o stave štruktúry a textúry dužiny, ktorej kvalita významným spôsobom prispieva k celkovej kvalite hodnotených plodov. Pre hodnotenie štruktúry bola využitá fraktálna analýza umožňujúca stanoviť fraktálnu dimenziu štruktúry dužiny. Fraktálnou dimenziou bola hodnotená degradácia štruktúry štyroch variánt jabĺk odrody Idared počas dlhodobého skladovania v normovaných podmienkach. Bol zistený vplyv skladovania na fraktálnu dimenziu pomocou regresných závislostí vyjadrujúcich pokles hodnoty fraktálnej dimenzie pri narastajúcom čase skladovania. Pomocou analýzy variancie bol potvrdený vplyv skladovania a vplyv variánt hnojenia na fraktálnu dimenziu. S využitím senzorickej analýzy bola stanovená súvislosť medzi fraktálnou dimenziou a deskriptormi kvality dužiny jabĺk. Fraktálna dimenzia vyjadruje štruktúrne a textúrne vlastnosti dužiny jabĺk.

Kľúčové slová: skladovanie; fraktál; jablká; textúra; štruktúra

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