ISTRAŽIVANJE DUGOTRAJNOG SKLADIŠTENJA JABUKE 
FRAKTALNOM ANALIZOM

FRAC TAL ANALYSIS OF THE LONG - TERM STORAGE 
INFLUENCE ON THE APPLE FLESH

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REZIME

Uticaj dugotrajnog skladištenja na kvalitet voća je istraživan od strane većeg broja naučnika u svetu. Tako su se Tu i Baerdemaecker (1997) bavili uticajem faktora koji su delovali na jabuke pre no što su došle na čuvanje i to za tri kultivara Glloser, Zlatni delišće i Jómagold, a Johnson i saradnici (2001) su analizirali kako se fizičke promene jabuka dešavaju pre i posle skladištenja.

U radu su prezentovani rezultanti promena nekih fizičkih veličina jabuka nakon skladištenja od 80 dana pri temperaturi vazduha od 1°C i relativnoj vlaznosti vazduha od 90%, pri sadržaju O2 u vazduhu od 1,0% i ugljen-dioksida od 3,0%, i to kultivara Angold, Melodie, Selena i Rezista. Metoda Bow-Counting (brojanje kvadrata) je korisna za obradu rezultata merenja fraktalnom analizom. Karakteristični parametri su:

- \( D_{BBW} \) - koji reprezentuje učešće „mesa”, ili vrste osnove jabuka,
- \( D_{BBW} \) - koji reprezentuje učešće pora i kapilara u „mesu” jabuke,
- \( D_{BBW} \) - koji reprezentuje učešće linija između pora (kapilara) i čvrste osnove jabuka.

Uzorak za istraživanje (ekspertmentalna aparatura je prikazana na slici 1) je dobijan tako što su plodovi sečeni na polovine, a za

1

To se radi o plodovima između pora (kapilara) i čvrste osnove jabuka.

Uslovima istražovanja (ekspertmentalna aparatura je prikazana na slici 1) je dobijan tako što su plodovi sečeni na polovine, a za
tin je sečen čips do 2 mm. Kapilari i čelije koje su pod mikroskopom vide čine strukturu „mesa” jabuke, te se skeniranjem površine preseka s pomoću digitalne kolor kamere i mikroskopa dobijaju sličice veličine 768x576 piksela. Odgovarajući softveri su kori

2

Stvari su se koristile za analizu promene gustine jabuka tokom skladištenja (slike 7, 8, 9 i 10). Kao zaključak se može reći da

3

Istovremeno, za veličinu \( D_{BBW} \) učestvuje sevidapodatoki vremena. Na osnovu analize se zaključuje da se kultivari Angold i Selena pona

4

Ja shiftaju slično u procesu čuvanja, a drugi grupi pripadaju Melodije i Rezista.

5

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Kljucen reći: jabuka, skladištenje, fraktal.

SUMMARY

The paper deals with a study of apple flesh of cultivars Angold, Melodie, Selena and Rezista during long term storage conditions. The method of fractal analysis is applied for study of the changes in the apple structure. Fractal dimension is determined as the parameter, which expresses the condition of the apple flesh. Fractal dimension is a non-integer number, which has relation to the fragmentation of the apple flesh structure and to its porosity. The dimensions DBW, DBBW and DBW, which characterized the border line among pores and particles of apple structure, particles and pores of apple flesh respectively, were evaluated by software HARFA. Dimensions were determined from of 40 – times magnified digital images of the apple flesh, which were taken by CCD camera from optical microscope. The dependencies of fractal dimensions on the time of storage and bulk density and the dependencies of bulk density on time of storage were determined.

Key words: apple flesh, storage, fractal

INTRODUCTION

The problems of the long – term storage of the fruit are of the subject large investigation. Tu and Baerdemaecker (1997) studied effects of prestorage heat treatment on the texture of three apple cultivars: Glosopher, Golden Delicious and Jonagold. Changes of apple firmness, extractable juice content, background, colour, soluble solids concentration and pH values were determined after 4 months cold storage. Johnson et al. (2001) studied the flesh firmness to assess apple quality before and after low temperature storage. Experiments were conducted to quantify physical change in apple texture readings with change in fruit temperature. Royal Gala, Granny Smith and Pacific Rose apple fruit were stored at 0 °C, while Cox’s Orange Pippin was stored at 3 °C. At different times during storage, flesh firmness and cortical tensile strength were measured on fruit at storage temperature. Firmness change with temperature was not affected by orchard or harvest maturity.

METHODS

Fractal analysis

Box-Counting method was used to evaluating of the fractal properties of the apple flesh texture. The method is often used to determine fractal box dimension of digitized images of fractal structures. Nežádal et al. (2001) and Buchniček et al. (2000) ha-
ve implemented Box-Counting procedure in software HarFA ver. 5.0, which analyses black&white images. Box-Counting method utilizes the covering fractal pattern with raster of boxes (squares) and than evaluating how many boxes of the raster are needed to cover fractal completely. Repeating this measurement with different sizes of boxes r = 1/e 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

\[
\ln N_{BW}(r) = \ln(K_{BW}) + D_{BW} \ln(r)
\]

(1)

\[
\ln N_{BBW}(r) = \ln(K_{BBW}) + D_{BBW} \ln(r)
\]

(2)

\[
\ln N_{WBB}(r) = \ln(K_{WBB}) + D_{WBB} \ln(r)
\]

(3)

give \( D_{BW} \), \( D_{BBW} \) and \( D_{WBB} \) the fractal dimensions. \( D_{BW} \) characterizes properties of border of fractal pattern (characterized the border line among pores and particles of the flesh). \( D_{BBW} \) characterizes fractal pattern on the white background (the particles or solid areas of the flesh) and \( D_{WBB} \) characterizes fractal pattern on the black background (the pores or low areas of apple flesh). \( N_{BW} \) is the number of black&white squares, which are found in the raster. \( N_{BBW} \) is the number of black&white and black squares, which are found in the raster and \( N_{WBB} \) is the number of black&white and white squares, which are found in the raster.

Samples and storage properties

Measurement was realized for apples of cultivars Angold, Melodie, Rezista and Selena. Experimental measurements were realized during of apple storage from 26\textsuperscript{th} November 2004 to 4\textsuperscript{th} Februr 2005. Three series of measurement were realized. Thirty values of fractal dimension were evaluated for each sample and cultivar. Together 270 experimental values of the fractal dimension for each cultivar. The new samples of apples were used for each measurement.

The storage was provided in the storage boxes at the temperature 1\textdegree C and 90 % of the air moisture content and with 1 % \( O_2 \) and 3 % \( CO_2 \).

Experimental measurement

Apple samples were always cut on two half parts and the section of the depth 2 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 surface on the changing of the apple flesh structure. \( D_{BW} \), \( D_{BBW} \) and \( D_{WBB} \) fractal dimensions were determined for surfaces of the area samples scanned by video microscope combined with colour digital CCD camera GKB CS-8606S with the array of size 768x576 pixels and trinocular microscope MI XSZ 107. The experimental equipment is shown in the Fig. 1.

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 HarFA ver. 5.0 was used for digital filtering of images and establishing of fractal dimension. The digitized samples were adjusted on the size 768x576 pixels with the resolution 38 pixels/cm. The forty times magnification was obtained. The real area of scanned surface was 3,4x3,4 mm for each digital image. The good contrast between black and white colour was achieved by graphic filtering on the digitized sample snapshots realized by HarFA's intensity tresholding.

The selected white colour represented the pores and the black the grains of the apple flesh. The pores and the grains of apple flesh were modeled by the squares of the size \( e \). The digitized samples were covered by raster of the side size square \( e \) (pixel). 27 rasters were used for each sample with one iteration. The raster was changed from 1 to 128 pixels in 27 steps and the occupation of the squares \( N_{BW}(e) \), \( N_{BBW}(e) \) and \( N_{WBB}(e) \) was always determined for each snapshot. Thirty digital snapshots of the sample structure were obtained from each apple sample. The number of squares was always determined and the fractal dimension \( D_{BW} \), \( D_{BBW} \) and \( D_{WBB} \) were established.

The bulk density \( p \) of cultivars was measured in dependency on the time of storage. The bulk density was measured from one apple by measurement its mass and volume. The bulk density was obtained from the equation

\[
p = \frac{m}{V}
\]

(4)

The mass \( m \) was measured with precision 0.01g. The volume \( V \) was measured with accuracy 8 ml. The bulk density was measured with precision 4 %.

OBTAINED RESULTS AND DISCUSSION

The arithmetical averages of the fractal dimensions were calculated. Each average was calculated from thirty values. The same procedure was realized for all series of the snapshots of the samples for all dimension. One series included 30 samples. The measurement of each cultivar included 90 snapshots for each sort of dimension, i.e. 270 snapshots for each cultivar. 1080 experimental values of fractal dimensions were used together.

The dependencies of fractal dimensions \( D_{BW} \), \( D_{BBW} \) and \( D_{WBB} \) on the time of storage were created.

The dependencies of the fractal dimensions \( D_{BW} \), \( D_{BBW} \) and \( D_{WBB} \) on the time of storage and their regression equations and coefficients of determination for cultivars Angold and Melodie are shown in the Figs 2, 3. The dependencies of the fractal dimensions \( D_{BW} \), \( D_{BBW} \) and \( D_{WBB} \) on the time of storage and their regression equations and coefficients of determination for cultivars Selena and Rezista are shown in the Figs. 4, 5.

The biggest values achieved \( D_{BW} \) fractal dimensions for all cultivars. \( D_{BBW} \) dimensions achieved medium values for all cultivars and \( D_{WBB} \) dimensions achieved the smallest values for all cultivars.

The dependencies of the fractal dimensions of cultivar Angold showed soft decreasing trend. \( D_{BBW} \) fractal dimension, which characterized the low areas of apple flesh or pores decreased. It means that representation of pores was decreased in dependency of time of storage.
D_{BW} fractal dimension was almost constant. It means also the representation of solid particles or grains of apple flesh was almost constant. D_{BW} fractal dimension which characterized border line among pores and grains of apple flesh was decreased.

The dependencies of the fractal dimensions D_{BW} and D_{WBW} of the cultivar Melodie had complementary character. When D_{BW} was decreased D_{WBW} was increased. D_{BW} fractal dimension was almost constant.

The fractal dimensions of the cultivar Selena showed soft decreasing trend similarly as dependencies of the cultivar Angold. The representations of the pores and grains of the apple flesh showed almost the same behavior like for the cultivar Angold.

The dependencies of the fractal dimensions D_{BW} and D_{WBW} of the cultivar Rezista showed also complementary character like dependencies of the cultivar Melodie but development of the dependencies D_{BW}, D_{WBW} was opposite. When D_{BW} was increased D_{WBW} was decreased. D_{BW} fractal dimension was almost constant.

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**Table 1. Regression equations of bulk density dependencies on time of storage**

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Regression equation</th>
<th>Coeff. of determination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angold</td>
<td>y = 0.0117x² - 0.7694x + 745.77</td>
<td>R² = 1</td>
</tr>
<tr>
<td>Melodie</td>
<td>y = -0.0053x² - 0.2343x + 747.49</td>
<td>R² = 1</td>
</tr>
<tr>
<td>Selena</td>
<td>y = 0.0184x² - 0.3602x + 701.98</td>
<td>R² = 1</td>
</tr>
<tr>
<td>Rezista</td>
<td>y = -0.0242x² - 1.3152x + 7.0124</td>
<td>R² = 1</td>
</tr>
</tbody>
</table>
The dependencies of the fractal dimensions $D_{BW}$, $D_{BBW}$ and $D_{BBW}$ on the bulk density are showed for the cultivars Angold, Melodie, Selena and Rezista in the Figs. 7, 8, 9 and 10.

The dependency of the fractal dimension $D_{BBW}$ of the cultivar Angold on the bulk density during of the storage was slightly increased (in the Fig. 7). The dependencies of the $D_{BW}$ and $D_{BBW}$ were at first increased and then decreased.

The dependencies of the fractal dimensions $D_{BBW}$, $D_{BBW}$ and $D_{BBW}$ on the bulk density for the cultivar Angold
Sl. 7. 7. Zavisnost promene fraktnih dimenzi $D_{BW}$, $D_{BBW}$ i $D_{BBW}$ od nasipne gustine kad jabuke Angold

The dependency of the fractal dimension $D_{BW}$ of the cultivar Melodie on the bulk density during of the storage was constant (Fig. 8). The dependencies of the $D_{BW}$ and $D_{BBW}$ were complementary. When $D_{BBW}$ was increased $D_{BBW}$ was decreased.

The dependency of the fractal dimension $D_{BBW}$ of the cultivar Selena on the bulk density during of the storage at first was slightly increased and then decreased (Fig. 9). The dependencies of the $D_{BW}$ and $D_{BBW}$ were soft decreased.

The dependency of the fractal dimension $D_{BW}$ of the cultivar Rezista on the bulk density during of the storage at first was almost constant (Fig. 10). The dependencies of the $D_{BBW}$ and $D_{BBW}$ were complementary. When $D_{BBW}$ was increased $D_{BBW}$ was increased.

**CONCLUSION**

The method of fractal analysis of the apples of the cultivars Angold, Melodie, Selena and Rezista 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 dependencies of the fractal dimensions $D_{BW}$, $D_{BBW}$ and $D_{BBW}$ on the time of storage could be used for determination of the representation of pores and grains of the apple flesh studied cultivars during the long term storage and so could determine the quality of the texture. The dependencies of the fractal dimensions $D_{BW}$, $D_{BBW}$ and $D_{BBW}$ on the bulk density could be used for determination of the bulk density studied cultivars during the long term storage. The dependencies could together faster determine the quality of the cultivars during long-term storage.

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MATHEMATIČKO MODELIRANJE KINETIKE OSMOTSKOG SUŠENJA VOĆNOG TKIVA
MATHEMATICAL MODELING OF THE OSMOTIC DRYING KINETIC OF FRUIT TISSUE
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REZIME
Matematički modeli koji opisuju kinetiku osmotskog sušenja voćnog tkiva, koriste se za projektovanje novih ili optimizaciju već postojećih procesa sušenja. Sušinsko razumevanje procesa od velikog je praktičnog i ekonomskog značaja. Zbog izuzetne složenosti matematičkog opisa, sušinskih fizičkih i hemijskih pojava pri osmotском sušenju, danas još uvek ne postoji opšte prihvaćen model osmotskog sušenja voćnog tkiva. Osnovna teškoća koja onemogućuje postavljanje matematičkog modela realnog procesa osmotskog sušenja na osnovu fundamentalnih zakona, sastoji se uglavnom u tome što ti zakoni opisuju odvojene, pojedinačne pojavе, a proces sušenja se sastoji od skupa međusobno uslovljenih i povezanih pojava. Izrazi kojima se pokušava obuhvati splet pojava, samo su približne realnim procesima koji se dešavaju unutar materijala koji se suši. U radu su diskutovana tri pristupa matematičkom modeliranju kinetike osmotskog sušenja voćnog tkiva konstatovana u literaturi; teorijski, poluteorijski i empirijski.

Kljuci reči: osmotsko sušenje, kinetika, matematičko modeliranje, voćno tkivo.

SUMMARY
Mathematical models that describe kinetic of the osmotic dehydration of the fruit tissue are used for projecting new drying processes or optimization of the already existing ones. Essential understanding process has great practical and economical importance. Due to the exceptional complexity of mathematical description of essential physics and chemical phenomena that appear during osmotic dehydration, there is no universal model for osmotic dehydration of fruit tissue. Basic problem that disables description of a mathematical model of real process consists mainly of the fact that basic laws describe separate, individual phenomena, until the drying process is a result of interaction of multiconditional phenomena. The equations which are aiming to comprehend such interaction are only on attempt to converge to the real process which is happening inside of the material.

The paper argues about three approaches of mathematical modeling of kinetic fruit tissue drying that can be recognized in literature: theoretical, semi-theoretical and empirical.

Key words: osmotic drying, kinetics, mathematical modeling, fruit tissue.

UVOD
Proces osmotskog sušenja predstavlja jednu od osnovnih tehnioloških operacija u ciklusu prerade voćnog tkiva kombinovanom tehnologijom (Babić Ljiljana, 2003, 2004; Babić M., 2004). Osmotsko sušenje je složena tehnološka operacija koja ima za cilj da očuva čitav niz prirodnih obreda materijala. Kako bi finalni proizvod bio što boljeg kvaliteta u pogledu fizičkih, strukturno-chemičkih i organoleptičkih pokazatelja. Očuvanje kvaliteta može se postići samo ako se kontroliše i upravlja mehanizmom prostranja toplate i materije koji se odvijaju u voćnom tkivu. Analizom kinetike osmotskog sušenja i matematičkim uobičavanjem rezultata analize dobijaju se esencijalne inženjeriske informacije o pomenutim mehanizmima. Zbog izuzetne složenosti matematičkog opisa fizičkih i hemijskih promena pri osmotskom sušenju, danas još uvek ne postoji opšte prihvaćen matematički model osmotskog sušenja voćnog tkiva. Osnovna teškoća koja onemogućuje postavljanje ovog modela realnog procesa osmotskog sušenja na osnovu fundamentalnih zakona, sastoji se u tome što ti zakoni opisuju odvojene, pojedinačne pojavе, a proces sušenja se sastoji od skupa međusobno uslovljenih i povezanih pojava. Izrazi kojima se pokusava obuhvati splet pojava, samo su približne realnim procesima koji se dešavaju unutar materijala koji se suši. Cilj ovoga rada je da na osnovu podataka iz literature ukaže na postojeće pristupe matematičkom modeliranju kinetike osmotskog sušenja, prikaže modele i predoči prednosti i mene analiziranih pristupa.

MATERIJAL
Osmotsko sušenje je složen proces prenosa mase - materije, koji se odvija između osmotskog rastvora i komada voća. Postoji