

## FRACTAL ANALYSIS OF THE FLOUR FRAKTALNA ANALIZA BRAŠNA

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### ABSTRACT

The aim of the paper was the evaluation of the microscopic, powder samples of flour by utilizing the fractal analysis. The powder particles were compared and submitted to fractal analysis. Three types of flour were studied, smooth flour, semi-flour and thick flour. The five samples of each sort of flour were tested by fractal analysis. The samples were digitized by the digital microscope Motic DM 1802-A with software Motic Image Plus ver. 2.0. Each image was processed by the thresholding operation and the fractal analysis was realized by the software Harfa ver. 5.1.0 and the samples were compared by the correlation analysis. The obtained fractal dimensions described the segmentation and distribution of flour powder and the fractions of the flour. The fractal dimension of the smooth flour was  $D_{WBW} = 1.29266$ , of the semi-flour  $D_{WBW} = 1.70734$  and of the thick flour  $D_{WBW} = 1.57978$ . The smooth flour was composed of microscopic powder particles of wheat. Small particles of about  $10 \mu\text{m}$  were mainly found in the smooth flour. However, sporadic particles greater than  $47.6 \mu\text{m}$  were also observed. The size of the smooth flour particles was from  $2.38 \mu\text{m}$  to  $47.6 \mu\text{m}$ . The semi-flour contained mainly particles the size of up to  $71.2 \mu\text{m}$ . Practically half the particles obtained from semi-flour were the size of up to  $71.2 \mu\text{m}$ . The thick flour was created mainly by particles to the size of  $73.78 \mu\text{m}$ . Greater particles, the size from  $130.9 \mu\text{m}$  to  $314.2 \mu\text{m}$ , were obtained in a small number. On the base of the particle distribution, the semi-flour and the thick flour were very similar, but on the base of fractal analysis they were different and we can distinguish them.

**Keywords:** powder, flour, fractal analysis

### REZIME

Cilj istraživanja bio je procenjivanje mikroskopskih, praškastih uzoraka brašna pomoću fraktalne analize. Čestice praha su upoređene i podvrgnute fraktalnoj analizi. Ispitivane su tri vrste brašna: meko brašno, polu poluoštro i oštro brašno. Pet uzoraka svake vrste brašna testirani su fraktalnom analizom. Uzorci su digitalizovani pomoću digitalnog mikroskopa Motic DM 1802-A sa softverom Motic Image Plus ver. 2.0. Svaka slika obrađena je operacijom praženja, a fraktalna analiza realizovana je softverom Harfa ver. 5.1.0, a uzorci su upoređeni korelacionom analizom. Dobijene fraktalne dimenzije opisale su segmentaciju i raspodelu praha brašna u prahu i frakcije brašna. Fraktalna dimenzija meko brašna iznosila je  $DVBV = 1,229266$ , poluoštrog brašna  $DVBV = 1,770734$ , a oštrog brašna  $DVBV = 1,57978$ . Glatko brašno je bilo sastavljeno od mikroskopskih čestica pšenice. Male čestice od oko  $10 \mu\text{m}$  nalaze se uglavnom u glatkom brašnu. Međutim, primećene su i pojedinačne čestice veće od  $47,6 \mu\text{m}$ . Veličina čestica glatkog brašna bila je od  $2,38 \mu\text{m}$  do  $47,6 \mu\text{m}$ . Poluoštro brašno je sadržavalo uglavnom čestice veličine do  $71,2 \mu\text{m}$ . Praktično, polovina čestica dobijenih iz poluoštrog brašna bila je veličine do  $71,2 \mu\text{m}$ . Oštra brašna bila su, uglavnom, od čestica veličine  $73,78 \mu\text{m}$ . Veće čestice, veličine od  $130,9 \mu\text{m}$  do  $314,2 \mu\text{m}$ , dobijene su u malom broju. Na osnovu raspodele čestica, poluoštro brašno i oštra brašna bili su vrlo slični, ali na osnovu fraktalne analize bila su različita i možemo ih razlikovati.

**Ključne reči:** prah, brašno, fraktalna analiza.

### INTRODUCTION

The quality of flour is influenced by the geometrical properties of the flour grains and their distribution. The quality of the flour depends on the compounds. Wheat flour is composed of proteins, starch, lipids, sugars and enzymes. The properties of flour are very important for the quality of cereals and bread. Wheat flour is generally used for bread making due to its gluten network structure that imparts excellent formation of cohesive, extensible, elastic dough and retention of gas during fermentation (Cappelli, Oliva, & Cini, 2020). Previous research into fine cereal flour fractions derived by various milling techniques revealed that particle size can largely affect the physicochemical properties of flours, such as water absorption, damaged starch content, pasting properties and thereby has a significant impact on dough rheological behavior and bread quality (Angelidis et al., 2016).

Particles of flour have different shapes and segmentation. It can be applied to the detection of different flours by the segmentation and fragmentation parameter – fractal dimension. Detection of flours on the base of the optical and fractal methods could be useful for the evaluation of the flour quality by the nonstandard method. Kim et al., (2004) studied the particle sizes

of soft and hard wheat (*Triticum aestivum* L.) flours at isothermal temperatures were determined by laser diffraction analysis. Flour samples were suspended in water at temperatures ranging from  $30$  to  $80 \text{ }^\circ\text{C}$ , for  $20$ – $60$  min. All flour particles exhibited trimodal size distributions, with the particles of the first mode  $<10 \mu\text{m}$ , the second mode from  $10$  to  $40 \mu\text{m}$ , and the third mode from  $41$  to  $300 \mu\text{m}$ . Control experiments with isolated starch and gluten indicated that the first and second modes were mainly associated with starch granules, while the third mode was related to gluten and particle clusters. Soft wheat flours showed higher volume fractions in the first and second modes, indicating more dissociated starch granules. Since, particle size, particle shape and surface roughness greatly influence the bulk and shear properties of the powders, various researches have been conducted to establish a relation between surface roughness and other properties like particle shape and particle size for different types of powders in various industries. Particle size has a major influence on powder flowability. The reduction in flowability at smaller particle size is due to the increased surface area per unit mass of powder (Shumaila et al., 2017).

Fractal dimension is a very important parameter for topographical measurement of various materials (Chen, 2007). It

is used in several applications, such as measurement of irregularities in an image, texture segmentation, surface roughness estimation and many other functions (Biswas, Ghose, Guha, & Biswas, 1998). The fragmentation of the powders can be evaluated by fractal analysis. Fractals are of a rough or fragmented geometric shape that can be subdivided into parts, each of which is (at least approximately) a reduced copy of the whole. They are crinkly objects that defy conventional measures, such as length and are most often characterised by their fractal dimension. They are mathematical sets with a high degree of geometrical complexity that can model many natural phenomena. Almost all natural objects can be observed as fractals (coastlines, trees, mountains, and clouds). Their fractal dimension strictly exceeds the topological dimension (Zmeškal, 2001). Fractal dimension is the number, very often non-integer, often the only one measure of fractals. It measures the degree of fractal boundary fragmentation or irregularity over multiple scales. It determines how fractal differs from Euclidean objects (point, line, plane, circle, etc.)

Just a small group of fractals have one certain fractal dimension, which is scale-invariant. These fractals are monofractals. Most natural fractals have different fractal dimensions depending on the scale. They are composed of many fractals with different fractal dimensions. They are called „multifractals“. To characterise a set of multifractals (e.g. set of different coastlines) we do not have to establish all their fractal dimensions, it is enough to evaluate their fractal dimension at the same scale (Mandelbrot, 1983; Theiler, 1990).

Dannenber (2002) found a much more sophisticated program call HarFA (harmonic fractal analysis) which creates some beautiful data, is very fast and allows a larger range of boxes to be analyzed. It calculates the fractal dimension spectrum as well, so you can see structure in the dimension *D* that corresponds to the particle size distribution and distribution of spacings between particle edges.

The objective of the manuscript was the evaluation of fractal properties of the microscopic, powder image samples of flour by utilizing the fractal analysis to distinguish the different flours by the fractal dimension. The application of quality control of the granularity of the flour can be realized.

## MATERIAL AND METHOD

The Box-Counting method was used for evaluating the fractal properties of the flour particle texture. The method is often used to determine the fractal box dimensions of digitized images of fractal structures. Nežádal et al., (2001) and Buchniček et al., (2000) have implemented the Box-Counting procedure in software called HarFA ver. 5.1.0. The HarFA software analyses black&white images. The Box-Counting method utilizes the covering fractal pattern with a raster of boxes (squares) and then evaluating how many boxes are of the raster. Repeating this measurement with different sizes of boxes  $\varepsilon = 1/r$  will result in the logarithmical function of box size  $\varepsilon$  and the number of boxes  $N(\varepsilon)$  needed to completely cover the fractal.  $\varepsilon$  is the size of the side of squares, which are covering the texture. The number of boxes is

$$N(\varepsilon) \sim \varepsilon^{-D} \tag{1}$$

and the fractal dimension *D*

$$D = -\lim_{\varepsilon \rightarrow 0} \frac{\ln N(\varepsilon)}{\ln \varepsilon} \tag{2}$$

The slopes of the linear functions give  $D_{BW}$ ,  $D_{BBW}$  and  $D_{WBW}$  fractal dimensions.

$$\ln N_{BW}(\varepsilon) = \ln(K_{BW}) + D_{BW} \ln(\varepsilon) \tag{3}$$

$$\ln N_{BBW}(\varepsilon) = \ln(K_{BBW}) + D_{BBW} \ln(\varepsilon) \tag{4}$$

$$\ln N_{WBW}(\varepsilon) = \ln(K_{WBW}) + D_{WBW} \ln(\varepsilon) \tag{5}$$

$D_{BW}$  characterizes properties of the border of fractal patterns.  $D_{BBW}$  characterizes a fractal pattern on a white background and  $D_{WBW}$  characterizes a fractal pattern on a black background.  $N_{BW}$ ,  $N_{BBW}$  and  $N_{WBW}$  are the numbers of squares covered black&white, black + black&white and white+ black&white squares.  $K_{BW}$ ,  $K_{BBW}$  and  $K_{WBW}$  are fractal measures of the dividing line.

Three commercial flours in Slovakia were studied: smooth flour (Wheat smooth Special 0Extra flour), semi-flour (Wheat semi-flour superior) and thick flour (Gold Spike).

Five samples were realized for each sort of flour. The flour was applied on the microscopic glass of the digital microscope Motic DM 1802-A (Motic, China) by imprinting of the glass to the flour. The software Motic image plus 2.0 was used for digitizing of the flour image samples. The calibration of the microscope was realized by the calibration glass with a scale of 0.1 mm (Fig.1). One hundred magnification of the microscope was applied. Dimensions of the images were 1280x1024 pixels. The length of the scale division 0.1 mm at 100 times magnification was 42 pixels and then one pixel was 2.38  $\mu\text{m}$ . The size of the flour particles was measured on the base of the scale.

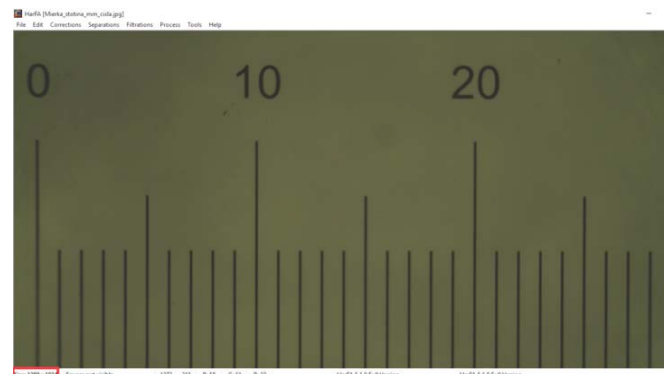


Fig. 1. Calibration glass with the scale 0.1mm as the image of size 1280x1024 pixels

The images of flour samples were evaluated in the software HarFA ver. 5.1.0. The original images were submitted to the thresholding intensity procedure. The thresholds of greyscale were determined for each sample image. Thresholding enabled the determination of the particles of the flour in the image sample. The inversion of the foreground and the background was realized, which was needed for the fractal analysis software. The fractal analysis of the image samples was realized on the base of the equations (3, 4 and 5). The image samples were covered by 28 square rasters with the square size from 1 pixel to 358 pixels and fractal dimensions were calculated from the slopes of the regression curves of the equations (3, 4 and 5).

## RESULTS AND DISCUSSION

The original image of the smooth flour sample no. 1 is presented in Fig. 2. The dark particles represent the grains of the flour. The software Harfa required the intensity thresholding of the images for the next evaluation. The thresholding created negative images of the original images on the base of thresholding intensity. The level of intensity threshold was from level 0 (black color) to level 255 (white color). The image of the

sample no.1 of the smooth flour after thresholding is shown in Fig. 3 with the intensity threshold of 25 and 255. Determination of the fractal dimensions of the smooth flour for sample no. 1 by the software HarFA is presented in Fig. 4. The fractal dimension of white grains of smooth flour on a black background was evaluated.



Fig. 2. Image of the sample of the smooth flour sample no. 1 before thresholding in the software HarFA

It means the white and black&white squares of the rasters were used and dimension  $D_{WBW} = 1.3076$  was determined from the slope of the straight line. The dimension  $D_{BW}$  represents the fraction of the border of the white flour grains and dimension  $D_{BBW}$  represents the fractionality of the black background. Flour was characterized only by the dimension  $D_{WBW}$ .

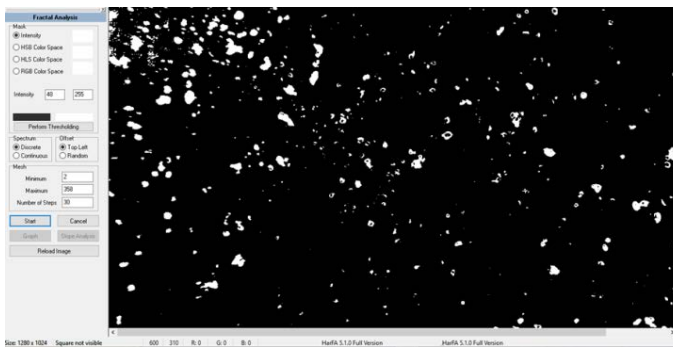


Fig. 3. Image of the smooth flour sample no. 1 after thresholding in the software HarFA. The threshold of intensity was 25 and 255.

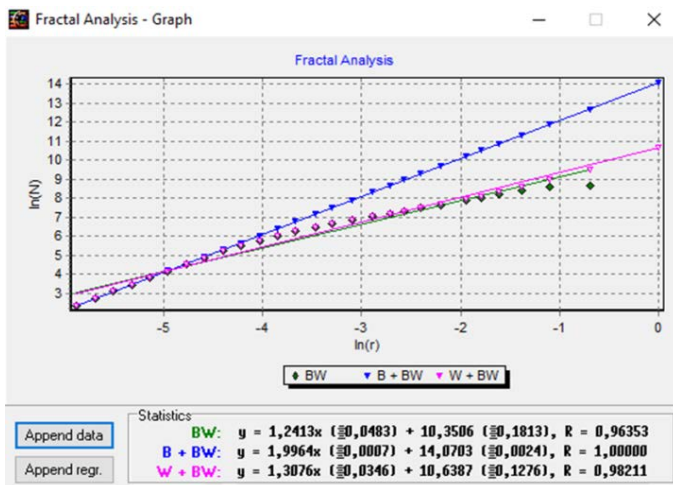


Fig. 4. Determination of fractal dimensions of the smooth flour of sample no. 1 from the slopes of the curves in the software HarFA

The results of the evaluation of the fractionality of the smooth flour are presented in the Tab. 1.

Table 1 Fractal dimensions of the smooth flour n – number of samples;  $D_{WBW}$  – fractal dimension of the flour particles; SD – standard deviation; K – fractal measure;  $SD_K$  – standard deviation; r – correlation coefficient r; CV – coefficient of variation.

n	$D_{WBW}$	SD	K	$SD_K$	r
1	1,3076	0,0346	10,6387	0,1276	0,98211
2	1,2392	0,0368	10,2879	0,1358	0,97754
3	1,3459	0,0372	10,8777	0,1371	0,98053
4	1,2561	0,0346	10,3557	0,1277	0,9806
5	1,3145	0,0354	10,6935	0,1307	0,98144
Average	1,29266	x	10,5707	x	x
SD	0,016103	x	0,089049	x	x
CV(%)	1,245747	x	0,842415	x	x

The smooth flour was composed of microscopic powder particles of wheat. Small particles of about 10  $\mu\text{m}$  were mainly found in the smooth flour. However, sporadic particles greater than 47.6  $\mu\text{m}$  were also observed. The size of the smooth flour particles was from 2.38  $\mu\text{m}$  to 47.6  $\mu\text{m}$ .

The original image of the semi-flour sample no. 1 is presented in Fig. 5. The image of sample no. 1 of the semi-flour after thresholding is shown in Fig. 6 with the intensity threshold of 47 and 255. Determination of the fractal dimensions of the semi-flour for sample no. 1 by the software HarFA is presented in Fig. 7. The fractal dimension of white grains of the semi-flour on a black background was evaluated. The dimension  $D_{WBW} = 1.7312$  was determined from the slope of the straight line. The dimension  $D_{BW}$  represents the fraction of the border of the white flour grains and dimension  $D_{BBW}$  represents the fractionality of the black background.

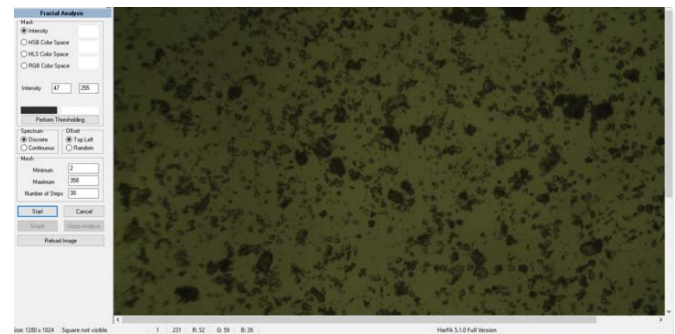


Fig. 5. Image of the semi-flour sample no. 1 before thresholding in the software HarFA

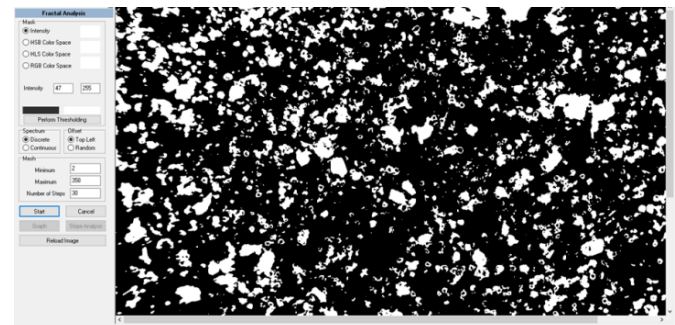


Fig. 6 Image of the semi-flour sample no. 1 after thresholding in the software HarFA. The threshold of intensity was 47 and 255.

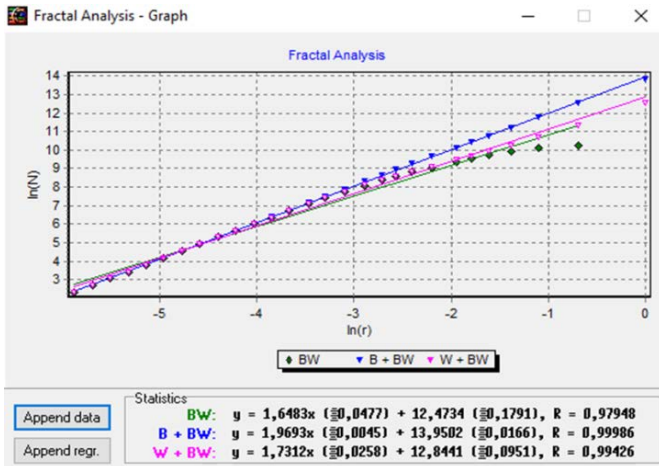


Fig. 7. Determination of fractal dimensions of the semi-flour of the sample no. 1 from the slopes of the curves in the software HarFA

The results of the evaluation of the fractionality of the semi-flour are presented in the Tab. 2.

Table 2 Fractal dimensions of the semi-flour  $n$  – number of samples;  $D_{WBW}$  – fractal dimension of the flour particles;  $SD$  – standard deviation;  $K$  – fractal measure;  $SD_K$  – standard deviation;  $r$  – correlation coefficient  $r$ ;  $CV$  – coefficient of variation.

n	$D_{WBW}$	SD	K	$SD_K$	r
1	1,7312	0,0258	12,8441	0,0951	0,99426
2	1,7309	0,0266	12,8461	0,0979	0,99392
3	1,7085	0,0276	12,7366	0,1016	0,99328
4	1,6815	0,0283	12,6011	0,1043	0,9927
5	1,6846	0,0287	12,6206	0,106	0,99249
Average	1,70734	x	12,7297	x	x
SD	0,00869	x	0,042521	x	x
CV (%)	0,508994	x	0,33403	x	x

Semi-flour contained mainly the particles of the size up to 71.2  $\mu\text{m}$ . Practically half the particles obtained from semi-flour were the size of up to 71.2  $\mu\text{m}$

The original image of the thick flour sample no. 1 is presented in Fig. 8. The image of the sample no.1 of the thick flour after thresholding is shown in Fig. 9 with the intensity threshold of 47 and 255. Determination of the fractal dimensions of the thick flour for sample no. 1 by the software HarFA is presented in Fig. 10. The fractal dimension of white grains of the smooth flour on a black background was evaluated. The dimension  $D_{WBW} = 1.5490$  was determined from the slope of the straight line.



Fig. 8. Image of the sample of the thick flour sample no.1 before thresholding in the software HarFA

The dimension  $D_{BW}$  represents the fraction of the border of the white flour grains and dimension  $D_{BBW}$  represents the fractionality of the black background.

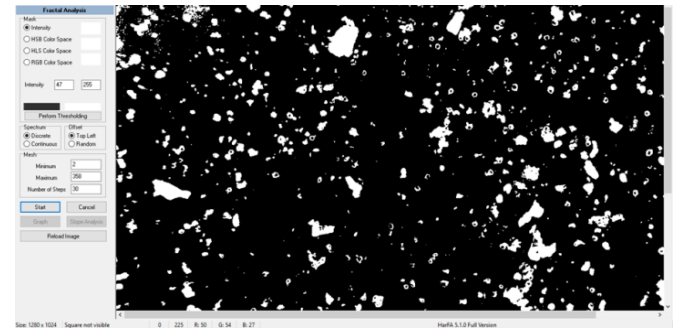


Fig. 9. Image of the sample of the thick flour sample no. 1 after thresholding in the software HarFA. The threshold of intensity was 47 and 255.

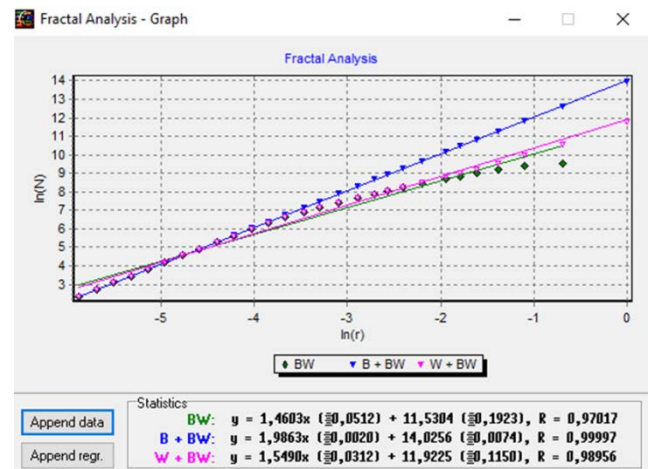


Fig. 10. Determination of fractal dimensions of the thick flour of the sample no. 1 from the slopes of the curves in the software HarFA

The results of the evaluation of the fractionality of the thick flour are presented in Table 3.

Table 3 Fractal dimensions of the thick flour  $n$  – number of samples;  $D_{WBW}$  – fractal dimension of the flour particles;  $SD$  – standard deviation;  $K$  – fractal measure;  $SD_K$  – standard deviation;  $r$  – correlation coefficient  $r$ ;  $CV$  – coefficient of variation.

n	$D_{WBW}$	SD	K	$SD_K$	r
1	1,549	0,0312	11,9225	0,115	0,98956
2	1,6552	0,0282	12,4634	0,1039	0,99251
3	1,6976	0,0267	12,6749	0,0986	0,99359
4	1,6921	0,0258	12,6397	0,0951	0,994
5	1,305	0,0324	10,5755	0,1193	0,98425
Average	1,57978	x	12,0552	x	x
SD	0,05466	x	0,288435	x	x
CV (%)	3,45999	x	2,392618	x	x

The thick flour was created mainly by the particles to the size of 73.78  $\mu\text{m}$ . Greater particles, of the size from 130.9  $\mu\text{m}$  to 314.2  $\mu\text{m}$ , were obtained in a small number.

## CONCLUSION

The obtained fractal dimensions described the segmentation and distribution of flour powder and the fractions of the flour. The fractal dimensions of the smooth flour were  $D_{WBW} = 1.29266$ , of the semi-flour  $D_{WBW} = 1.70734$  and of the thick flour  $D_{WBW} = 1.57978$ . The smooth flour was composed of microscopic powder particles of wheat. Small particles of about  $10 \mu\text{m}$  were mainly found in the smooth flour. However, sporadic particles greater than  $47.6 \mu\text{m}$  were also observed. The size of the smooth flour particles was from  $2.38 \mu\text{m}$  to  $47.6 \mu\text{m}$ . Semi-flour contained mainly particles the size of up to  $71.2 \mu\text{m}$ . Practically half the particles obtained from semi-flour were the size of up to  $71.2 \mu\text{m}$ . The thick flour was created mainly by particles to the size of  $73.78 \mu\text{m}$ . Greater particles, the size from  $130.9 \mu\text{m}$  to  $314.2 \mu\text{m}$ , were obtained in a small number. On the base of the particle distribution, the semi-flour and the thick flour were very similar, but on the base of fractal analysis they were different and we can distinguish them.

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