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Porosity of Deep Fat Fried Breaded Chicken Meat

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Summary

Effects of the addition of rice starch and dietary fibres (pectin and Fibrex) on the porosity of basic frying mixture formulations (corn flour, salt, spices) and oil uptake of coated chicken meat have been evaluated. Porosity of the fried breaded chicken meat was calculated from particle and bulk density. Pore size and particle size distribution were determined using microscopy image analysis and particle density by mercury intrusion porosimeter (MIP). Since there is a wide range of particle diameters, significant differences in pore size distribution were found. Also, pore structure appeared to be affected by oil absorption. Mercury entrapment in pores decreased significantly during 8 min of frying. The obtained results show that porosity of the samples is different for different frying mixture formulations and indicate that there is a difference in the extent of oil uptake for different formulations due to film forming capabilities of dietary fibres (pectin and Fibrex).

Key words: porosity, oil absorption, deep fat frying, chicken meat

Introduction

In recent years, popularity of battered and breaded food products has grown. Consumers like the taste, colour, appearance, and crispiness of breaded fried food. The use of batter and breading formulations on chicken meat has increased remarkably since the 1990s, and such products constitute the largest segment of the further processed poultry market in Croatia.

Deep fat frying is a complex and important operation, widely used in the food industry as well as in institutional preparation of food (*1*). Major disadvantage of fried foods is their high fat content. Reduced fat foods are now being in increasingly high demand by consumers due to health concerns, so there is a need to limit oil consumption and calories originating from fat (*2*). Aiming to decrease the fat in fried foods, many researchers have investigated the mechanisms of oil absorption, factors affecting oil uptake (*3*) and examined the use of hydrocolloids for coating foods or incorporating them into batter or frying mixture formulations before frying to reduce oil absorption (*4–6*).

The porosity of the product formed during frying plays an important role in the oil uptake. The mechanical, textural, and sensory properties of food are influenced by porosity and pore size distribution within the solid food matrix (*7,8*). Pores occur in a variety of food products and have a significant effect on their quality. They also have a direct effect on the physical properties, such as mass diffusion coefficient, thermal conductivity, and thermal diffusivity (*9*). Therefore, the information on pores is important for evaluating the quality of a food product, and modelling heat and mass transfer during food processing. Heating during deep fat frying

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can result in protein denaturation, shrinkage and collapse of pore structures. Thermal processing of meat affects its structural properties. McDonald and Sun (*10*) reported a change of porosity as a result of rapid cooling during vacuum cooling of cooked beef, while Kassama *et al.* (*11*) describe a change in porosity in pan fried comminuted meat as a result of cooking.

There are studies in the literature showing the effects of different frying mixture formulations on oil absorption. Shih and Daigle (*12*) found that rice flour resisted oil absorption better than wheat flour, but it was less effective as a thickening agent than wheat flour. The addition of pregelatinized rice flour resulted in increased oil absorption because of the porous nature of the fried product (*13*). Yusnita *et al.* (*14*) reported that combination of wheat flour with sago and rice flour could reduce cooking loss of the final product. Llorca *et al.* (*15*) showed that during frying process the leavening agent in the frying mixture is responsible for the production of CO_2 and the release of water vapour, which in turn make pores and channels in the structure.

Porosity and pore size distribution are important parameters during transport (diffusion) of water in food materials such as coated chicken meat (*16*). The nature of pretreatment, processing and the type of product significantly influence pore size, their geometry or shape, as well as pore size distribution within the matrix of breaded chicken meat (*17*). The knowledge of the pore structure is significant for new product development partially based on oil absorption. Hence, it can be utilized in modelling of technological process and mass transport control of deep fat frying and chemical reactions (*18*).

The main objective of this paper is to evaluate the effect of initial porosity of a frying mixture and coated chicken meat product on oil absorption and to characterize changes in both porosity and density during the process. Another aim of this investigation is to use mercury intrusion porosimetry to characterize the evolution of pore structure during deep fat frying of breaded chicken meat.

Materials and Methods

Raw materials

Deboned chicken breast meat (*pectoralis major*) used for coating with frying mixtures was purchased from a local supplier. Pectin is used as one of the most common dietary fibres, which is usually extracted from citrus fruits. Fibrex is a commercial product made from sugar beet. Hemicellulose and cellulose make 75 % of Fibrex and the rest of it consists of pectin from citrus. It has very high water holding capacity and stability at both high and low temperatures (frying, freezing, *etc.*). Pectin and Fibrex were purchased from Danisco, Denmark.

Salt was obtained from Solana Pag Ltd, Croatia and extruded corn flour from Naše klasje plc, Croatia. Rice starches Remyline XS-FG-P 75 % and Remyline AX-FG-P 25 % were purchased from Remy n.v., Belgium.

Spices used in research were coriander, curry, white pepper, black pepper, chile, ginger, rosemary, paprika, marjoram, garlic and cardamom. All were purchased from local market.

Sample preparation

Chicken meat was sliced to the dimensions of 3×3×1 cm (±10 %). Basic frying mixtures consisted of extruded corn flour, salt and different types of spices. Blends of corn flour, salt and spices were mixed at three different ratios (B1, B2 and B3), as presented in Table 1. The fry-

Table 1. Composition of frying mixtures

N(sample)	Mixture	*w*(extruded corn flour)/%	*w*(salt)/%	*w*(spice mixture)/%	*w*(rice starch)/%	*w*(pectin)/%	*w*(Fibrex)/%
1	B1 R1 P	50.5	12.0	22.5	6.0	9.0	–
2	B1 R2 P	50.5	12.0	22.5	8.0	7.0	–
3	B1 R3 P	50.5	12.0	22.5	10.0	5.0	–
4	B2 R1 P	45.5	22.5	17.0	6.0	9.0	–
5	B2 R2 P	45.5	22.5	17.0	8.0	7.0	–
6	B2 R3 P	45.5	22.5	17.0	10.0	5.0	–
7	B3 R1 P	40.5	22.5	22.0	6.0	9.0	–
8	B3 R2 P	40.5	22.5	22.0	8.0	7.0	–
9	B3 R3 P	40.5	22.5	22.0	10.0	5.0	–
10	B1 R1 F	50.5	12.0	22.5	6.0	–	9.0
11	B1 R2 F	50.5	12.0	22.5	8.0	–	7.0
12	B1 R3 F	50.5	12.0	22.5	10.0	–	5.0
13	B2 R1 F	45.5	22.5	17.0	6.0	–	9.0
14	B2 R2 F	45.5	22.5	17.0	8.0	–	7.0
15	B2 R3 F	45.5	22.5	17.0	10.0	–	5.0
16	B3 R1 F	40.5	22.5	22.0	6.0	–	9.0
17	B3 R2 F	40.5	22.5	22.0	8.0	–	7.0
18	B3 R3 F	40.5	22.5	22.0	10.0	–	5.0

ing mixtures also contained rice starch (in mass fractions of 6, 8 and 10 %) and dietary fibres (pectin or Fibrex) in mass fractions of 5, 7 and 9 %, as presented in Table 1.

Frying

Samples were fried in palm oil (Euroalfa, Zagreb, Croatia) in a programmable deep fat fryer (Philips, Model Essence HD 6180, the Netherlands). Fresh palm oil (2.5 L) was heated at 180 °C. A mass of 100 g of meat slices was coated with frying mixture, randomly placed in a wire basket and kept submerged for the required time (6 and 8 min). Fried samples were cooled at room temperature, weighed on a balance (Sartorius, GP 4102, UK) and placed in plastic sample bags with hermetic seals.

Porosity, bulk density and particle density

Porosity (ε), measured as the volume fraction of the air or the void spaces in the material of the sample, was calculated as follows:

$$\varepsilon = 1 - \frac{\rho_b}{\rho_p} = \frac{V_{air}}{V_{sample}} \cdot 100 \qquad /1/$$

where ρ_b is bulk density, ρ_p is particle density, V_{air} is the volume of the air and V_{sample} is the volume of the solid part of the sample.

Bulk density of the frying mixture was calculated by dividing the sample mass by the overall volume, which was measured using a 100-mL volume graduated cylinder (*19*). Bulk density of the meat coated with frying mixture (sample) was measured using liquid paraffin applying the following method: liquid paraffin was filled into the cylinder up to 80 mL mark, the sample was placed into paraffin and the difference between the two volumes was measured.

Particle density was derived by dividing the sample mass by the particle volume determined by mercury intrusion porosimeter (MIP) (Porosimeter Carlo Erba, Instruments WS 2000, Milano, Italy) at (22±1) °C and 200 MPa. Accessible cylindrical pore radius (contact angle of 140 degrees, surface tension 0.480 N/m) was in the range of 3.7–7500 nm.

Samples were weighed, placed in a vacuum pycnometer (less than 10 mmHg pressure) and loaded with mercury up to the mark. Loaded pycnometer was weighed and transferred into the high pressure cell and mercury intrusion was performed up to the 198 MPa pressure, followed by decrease of pressure at a rate of 1.9 MPa/s. The volume of the pycnometer bulb was 33.618 cm^3, typical sample mass was (10±2) g, and measurable volume of the intruded mercury was 2 cm^3. Cylindrical pore geometry was used in the calculations (Milestone 2000 software).

Image analysis and particle size distribution

Frying mixtures were placed on the glass slide and images were made using the microscope with digital camera DX51 (Olympus, Japan). For taking pictures and phase analysis, stereo zoom magnifier EZX12 (Olympus, Japan) together with digital camera Olympus DP71 was used. Phase analysis of microscopic images was done using the software Image Analysis Pro 5.0 (Olympus Soft Imaging Solutions GmbH, Germany), which uses contrast between the two phases (pores and solid part) of the image. Scanned colour image was first converted to dark phase (positive contrast) and after that to bright phase (negative contrast). Using bars of known lengths, pixel values were converted into distance units. The largest possible rectangular cross-section of the sample halves was cropped. After adjusting the threshold, area-based pore size distribution, median pore diameter and pore area as the fraction of the total area were determined using the Image Analysis software.

Lipid content

Lipid content of the samples was determined on dried samples using a combined technique of successive batch and semicontinuous Soxhlet extractions. Batch extraction was performed with ethyl ether, followed by a Soxhlet extraction (*20*). Oil absorption in the samples was calculated as follows:

$$w(\text{lipid}) = \frac{m(\text{extracted oil})}{m(\text{sample before extraction})} \cdot 100 \qquad /2/$$

where w(lipid) is the lipid content of the samples.

Texture analysis

Hardness of the fried samples was measured using the texture analyzer TA.HDPlus (Stable Micro Systems, UK). For penetrating into the sample, probe P/6 and Blade set were used. Testing parameters were 1 mm/s for testing speed and 20 mm for depth of penetration.

Statistical analysis

Experimental data were defined by Statistica 6.0 analysis of variance and covariance (ANOVA/ANCOVA) to determine the significant differences between porosity at different frying times (180 °C, for 6 and 8 min) ($p<0.01$). The influence of oil absorption on porosity was determined with the same method at different frying times.

Results and Discussion

Parameters describing bulk density and pore structure of the samples measured using mercury porosimeter are presented in Table 2. Porosity of fried samples tended to decrease with frying time (Table 3). Pinthus *et al.* (*3*) explained the influence of oil uptake on porosity, suggesting that the final reduction of the pore size and diameter was a result of the increased oil uptake.

Porosity ranged from 38.94 to 17.43 % for samples fried at 180 °C for 6 min and from 35.96 to 12.25 % for samples fried at the same temperature for 8 min (Table 3). Rahman *et al.* (*9*) also showed similar behaviour of fried fish muscles. Effect of oil uptake on total pore volume is evident, keeping in mind that the oil uptake increases with frying time. Thus, penetration of oil between inter-fibre muscle and connective tissues (collageneous fibre) is complete and the measured pores are those on the surface. Bailey and Light (*21*) noted that muscle fibres range from 10 to 100 μm in diameter, while Aguilera and Stanley (*22*) reported 0.1 μm diameter for collagen fibres of muscle tissues.

Table 2. Bulk and particle density of the samples heated at 180 °C for 6 and 8 min

N(sample)	Mixture	ρ_b/(kg/m^3)		ρ_p/(kg/m^3)	
		6 min	8 min	6 min	8 min
1	B1 R1 P	801.5	806.6	1144	1206
2	B1 R2 P	785.5	905.2	1168	1213
3	B1 R3 P	715.0	899.3	1171	1202
4	B2 R1 P	859.0	815.6	1143	1128
5	B2 R2 P	772.1	1013.0	1161	1227
6	B2 R3 P	791.0	921.9	1150	1135
7	B3 R1 P	820.0	950.8	1155	1181
8	B3 R2 P	888.4	780.0	1179	1218
9	B3 R3 P	905.7	988.3	1154	1135
10	B1 R1 F	845.8	967.2	1144	1196
11	B1 R2 F	716.2	777.1	1118	1134
12	B1 R3 F	951.2	902.5	1152	1096
13	B2 R1 F	851.0	899.1	1131	1147
14	B2 R2 F	757.7	100.4	1152	1242
15	B2 R3 F	717.7	961.7	1138	1096
16	B3 R1 F	901.1	924.5	1148	1153
17	B3 R2 F	857.5	852.0	1160	1124
18	B3 R3 F	827.5	898.4	1150	1130

Table 3. Porosity of the samples heated at 180 °C for 6 and 8 min

N(sample)	ε/%	
	6 min	8 min
1	29.9	33.1
2	32.7	27.1
3	38.9	25.1
4	24.8	27.6
5	33.4	17.4
6	31.2	18.7
7	29.0	19.4
8	24.6	35.6
9	21.5	12.9
10	25.8	19.1
11	35.9	31.4
12	17.4	17.6
13	24.7	21.6
14	34.2	19.1
15	36.9	12.2
16	21.5	19.8
17	26.0	24.2
18	28.0	20.5

Total surface area of particles, pore structure as a function of particle area and pore size separated (μm) in frying mixture are presented in Fig. 1. Total surface area of particles and structure of frying mixture as a function of particle size (μm) is presented in Fig. 2 for different frying mixtures.

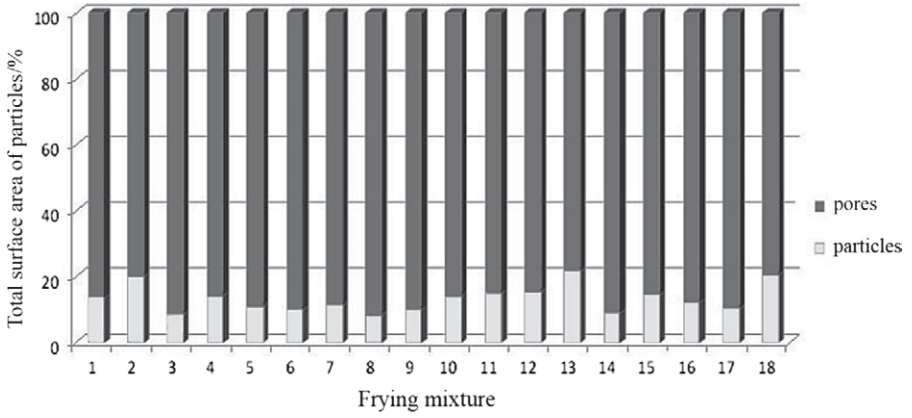

Fig. 1. Total surface area of particles and pores in frying mixtures

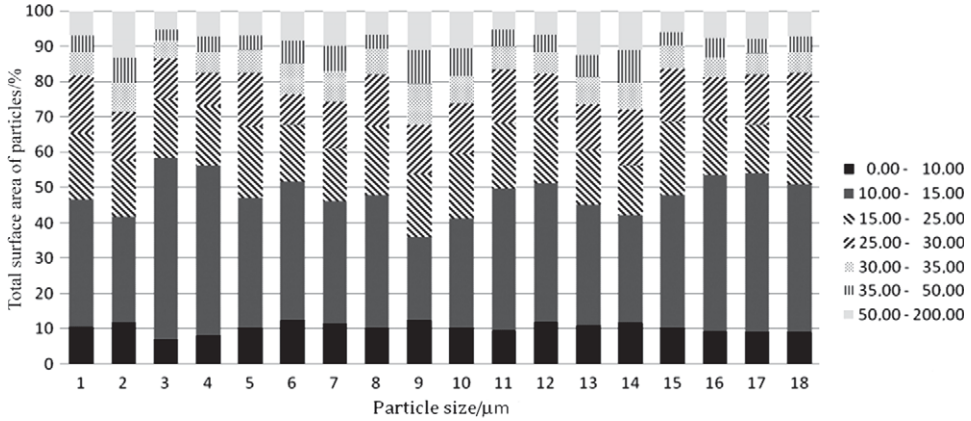

Fig. 2. Total surface area of frying mixture particles

Total surface area of particles from frying mixture contained in a mass unit of the sample was computed on the basis of accumulation of particle area. It was used to characterize particle size distribution as a function of the particle size (μm) of frying mixture (*23*). Fig. 2 shows the total particle surface area distribution in frying mixture (particle size within the mixture ranges from 1 to 200 μm). Olympus Soft Imaging Solutions GmbH uses contrast in scanned microscope image to find the edges of pores and particles, and defines regions representing voids and particles (Fig. 3). The use of raw materials with different particle size to form frying mixtures for battered, breaded, and fried chicken breasts resulted in different characteristics of the coatings. According to Maskat and Kerr (*24*), with the increase of particle size of raw material used for frying mixtures, coated surface became rougher and less uniform. Hardness of the frying mixtures increased with increasing particle size of raw material. Colour of the coatings became darker when frying mixture with larger particle size was used.

According to Rahman *et al.* (*9*) particle size distribution of chicken meat is more uniform than that of tuna and beef, and this may be attributed to the structural layout of the muscle fibres and their random orientation, which indicates that the majority of pores in deep fat fried coated chicken meat are capillary pores.

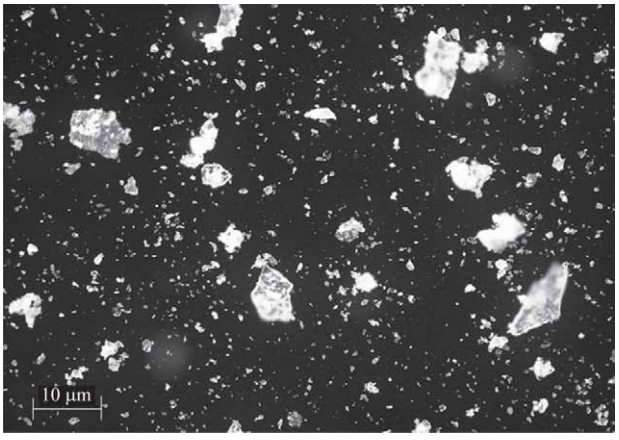

Fig. 3. Image of frying mixture analyzed with software Image Analysis Pro 5.0

The obtained data show that throughout the frying process, porosity of the sample fried at 180 °C for 6 min was greater than of the sample fried at 180 °C for 8 min. The difference in porosity indicates that there was a difference in the mechanism of oil uptake between the sample heated at 180 °C for 6 min and that heated at the same temperature for 8 min. This difference was also related to the film forming capability of the various frying mixtures, which may provide an explanation for the effectiveness of the combination of ingredients such as rice starch and dietary fibre (Fibrex and pectin) as oil uptake reducers. Increase of rice starch leads to decrease of oil uptake, as seen in Fig. 4. Although dietary fibres alone enhance oil uptake, their combination with starch still leads to the decrease of porosity and oil uptake, although in lesser extent. Effect of reduced porosity has, in addition to increased interfacial tension effect, been demonstrated previously (*3*). This emphasizes the importance of the composition of frying mixture for dynamic control of porosity and oil uptake during deep fat frying. Relationship between porosity and oil uptake is quite complicated, although higher initial porosity should increase oil uptake, it consequently results in reduced porosity. Moreira *et al.* (*25*) reported that bulk density decreased, while porosity and oil uptake increased with frying time during frying of tortilla chips.

Physical changes due to prolonged frying might cause pore volume to decrease. Deterioration of the collageneous connecting tissues due to heat may result in bulk shrinkage, swelling, denaturation, gelation and agglomeration of protein. Apart from the loss of water and oil uptake during deep fat frying, this has contributed to the modification of pore structure.

Oil uptake also influences the reduction of volume of pore space. Denaturation of proteins leads to reduction of pores in meat as a result of structural collapse (*9,26,27*). As the structural collapse is minimized with the oil uptake, this could be a limiting factor (*11*).

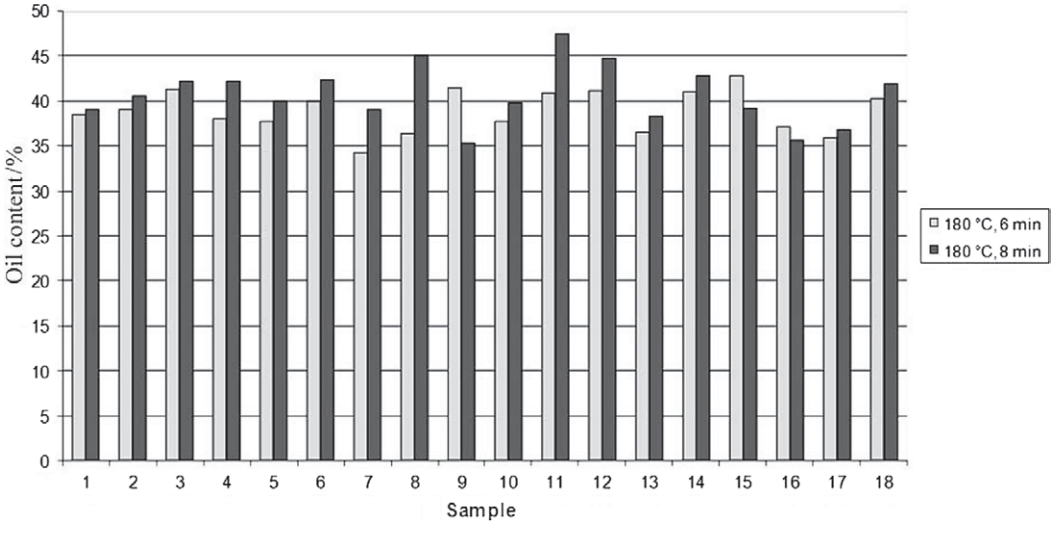

Fig. 4. Oil uptake of samples for different frying times

Effect of deep fat frying conditions on the oil uptake of samples (Fig. 4) shows that content of oil is lower when frying for 6 min than when frying for 8 min. The amount of oil absorption as a result of frying time affects porosity, because longer frying, as a thermal treatment, causes physical and chemical changes in the structure of frying mixture and meat during heating. Formation of uniform coating on the surface of chicken meat is primarily a method of limiting mass transfer of oil during frying.

Experimental data were elaborated with the analysis of variance and covariance (ANOVA/ANCOVA) using software Statistica 6.

Statistical significance of parameters that affect the change of porosity (time and content of oil) is expressed with p-value ($p<0.01$) (Table 4). In Table 5, the results for mean values of porosity are presented for different times with standard deviations. p-Value showed that with different time of frying, a significant change of porosity occurred (porosity decreased during longer period of frying) (Table 6).

Table 4. Results of statistical analysis test (ANOVA/ANCOVA)

ANOVA/ ANCOVA	dF effect	MS effect	dF error	MS error	F	p
t/min	1	510.2453	33	33.72429	15.12990	0.000460
Oil content	1	66.5687	33	33.72429	1.97391	0.169377

Table 5. Descriptive statistics of average values with standard deviations of porosity for different frying times

Effect	Level of factor	N	ε/%				
			Mean	S.D.	S.E.	–95.00 %	+95.00 %
Total	–	36	25.6	6.9	1.2	23.2	27.9
t/min	6	18	28.7	5.9	1.3	25.8	31.7
t/min	8	18	22.4	6.6	1.5	19.1	25.7

N=degree of freedom
S.D.=standard deviation
S.E.=standard error

Table 6. Univariate test of significance for porosity

Effect	SS	Degree of freedom	MS	F	p
t(6,8 min)	358.34	1	358.34	9.1513	0.004709

LS mean (within-group mean) values of porosity of variance are shown in Table 5, where it can be seen that variances do not correspond. This is confirmed by statistical data elaboration, *i.e.* the results of statistical analysis show that different times of frying had a significant influence on the change of porosity.

Conclusions

The porosity of samples decreased with prolonged frying time as a result of oil uptake, denaturation of proteins and other factors. Maximum porosity of samples fried at 180 °C for 6 min was 38.94 % and minimum was 17.43 %, while the minimum and maximum porosity of samples fried for 8 min were 12.2 and 36.0 %, respectively. Statistical analysis shows that frying time had significant influence on the porosity of samples ($p<0.01$). During frying, oil uptake filled the pores of the samples, thus forming a composite structure in interaction with muscle fibres. As a result of longer time of frying, oil content in the samples increased, which consequently influenced the decrease of porosity. Results of descriptive statistics were presented as mean values of porosity and indicated that frying time of 6 min significantly decreased porosity. Total surface area of particles, which was calculated using the particle size distribution bars, showed that particles fall in the range of 1–200 μm.

Since porosity varies for different types of frying mixture formulations, it leads to a conclusion that a difference in the extent of oil uptake is a consequence of film forming abilities of various ingredients. The composition of frying mixture is an important parameter for porosity determination in fried foodstuffs.

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