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# THE EFFECT OF PROCESSING METHOD ON DRYING KINETICS OF *PETROVSKÁ KLOBÁSA*, AN ARTISAN FERMENTED SAUSAGE

*The drying behaviour of dry-fermented sausage Petrovská klobása ripened in traditional and industrial conditions has been studied. The obtained results indicated that sausages dried in an industrial room (batch I) had higher weight loss and lower water activity ($a_w$) values than counterparts from traditional/artisanal production (batch T). Difference in drying intensity between internal and external fractions of sausages was much more marked for batch I. The experimental data of water content in Petrovská klobása, dried in respective conditions, were compared with values predicted by seven different mathematical models. Comparing the coefficient of determination ($r^2$), root mean square error ($E_{RMS}$) and the reduced chi-square ($\chi^2$) values of all equations, it was concluded that the Page mathematical model satisfactorily represents drying characteristics of Petrovská klobása both in traditional (0.990; $2.22\times10^{-2}$ and $6.01\times10^{-4}$, respectively) and industrial conditions (0.995; $1.79\times10^{-2}$; $3.91\times10^{-4}$, respectively).*

*Keywords: Petrovská klobása, drying condition, sausage fraction, mathematical model.*

Distinct cultural and social backgrounds of the populations and the environmental/climatic conditions in different geographical regions, determine greatly the physical and sensorial characteristics of each country style dry-fermented meat product. Thus, a great variety of fermented sausages are produced in European countries and many of them have been granted PDO (Protected Designation of Origin) and PGI (Protected Geographical Indication) labels [1,2]. Unfortunately, production and composition figures for these products are difficult to obtain, particularly because many of fermented sausages are produced and consumed locally and quantities are not recorded. The limited number of references available would suggest that the production, sale and consumption is sizeable, and it provides a decisive economic input to many rural regions [3,4]. This is the case for *Petrovská klobása,* traditional dry-fermented sausage made in an area nearby town of Bački Petrovac in the Autonomous Province of Vojvodina (Northern Serbia). It is a part of the Slovaks' heritage, who inhabited Vojvodina in the second half of 18th century. Nowadays, they are producing Petrovská klobasá in traditional way according to the original recipe of their ancestors. In traditional conditions, this sausage is made in the end of November and during December. This is when temperatures are around 0 °C or lower. Drying and ripening process lasts about 120 days, until it achieves specific and recognizable quality. Due to its savoury taste, aromatic and spicy-hot flavour, dark red colour and hard consistency *Petrovská klobása* is highly appreciated by consumers and it has a Protected Designation of Origin (PDO) under Serbian law [5].

The main processing mechanism for preserving purposes in artisanal dry fermented sausage production (no additives and starter addition) is based on water activity ($a_w$) reduction of the product. This $a_w$ reduction is achieved through both dehydration promoted during drying/smoking and salt addition to the formulation. Although many fermented sausages are commonly produced in industrial plants, there still are

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regions in Europe where these products are obtained through traditional technologies because they have a unique and much appreciated flavour. However, the traditional processes are very time consuming. Drying is the limiting step of the process in terms of time. A shortening of the drying period would result in a reduction of the drying facilities, capital and labour, and would increase the profit margin and the product competitiveness while reducing some safety concerns, such as mould growth, lipid oxidation and mite infestation [1,2,6].

Modelling the drying behaviour of different agricultural and food products often requires the statistical methods of regression and correlation analysis. Linear and non-linear regression models are important tools to find the relationships between different variables [7]. Due to the complex composition of meat products a theoretical prediction of drying curves is not possible, and drying data must be determined experimentally. Finding the appropriate model relating the drying time and moisture content is of great importance for defining the drying process and consequently the overall quality of food product.

In order to adapt traditional technology to industrial conditions and to shorten the drying period of this dry-cured meat product, the study was undertaken to determine whether sausages alternatively ripened in industrial room have different drying characteristics when compared to those counterparts from traditional/artisanal production. Moreover, development of mathematical models for describing drying process has been performed.

## MATERIAL AND METHODS

### Preparation of *Petrovská klobása*

*Petrovská klobása* dry fermented sausages were manufactured from a mixture of lean minced pork (80%) and pig fat (20%) obtained from carcasses of large white cross breed animals. After grinding the meat and the fat to a size of about 10 mm (with adjustable plate holder diameter set), raw materials were mixed with seasonings (red hot paprika powder, salt, raw garlic paste, caraway and sucrose) for about 10 min. The seasoned batter was immediately stuffed in collagen casings (500 mm long and 55 mm in diameter) and raw sausages were entirely processed in traditional smoking/drying room (batch T) or, alternatively, in an industrial ripening room (batch I) during 120 days. The ambient conditions in traditional room, which are highly dependent on outdoor climate conditions, were followed up regularly during the drying and ripening process. The traditional room temperature ranged from 2.6 to 12.4 °C, the relative humidity (RH) ranged from 43.3 to 93.0% while the air velocity ranged from 0 to 0.5 m/s. The low temperature (≈4 °C) and high relative humidity (≈90%) were characteristic for the first two months of production, while the subsequent period of drying and ripening was characterised by higher temperature (≈10 °C) and lower relative humidity (≈75%). Batch I sausages were smoked in industrial room for 3 days (10 °C, 90% RH and 0.5-‑0.6 m/s), dried in the same room at 10 °C, 75% RH and 0.5-0.6 m/s for 27 days and after that ripened in the same conditions but with minimal air circulation. Such thermo-hygrometric conditions in the industrial room (10 °C and 75% RH) were set to imitate conditions present in traditional practice (low temperature) and, at the same time, to enable faster drying (low RH, air circulation), in order to shorten the production period of this sausage [6].

### Samples

Samples of batches T and I were taken before stuffing (at day 0) and during processing (on days 2, 4, 6, 9, 12, 15, 30, 45 - just batch I, 60, 90 and 120). On each sampling occasion, three sausages from each batch were taken for water activity ($a_w$), moisture and ash content determination. For all the sausages, two concentric fractions were made, the more internal one with 25.4 mm in diameter and the external circular crown with the rest to full diameter (55 mm) of sausage (Figure 1). Therefore, three samples were obtained from each sausage (whole sausage and two fractions representing radial samples) which were independently homogenized prior to analysis mentioned above.

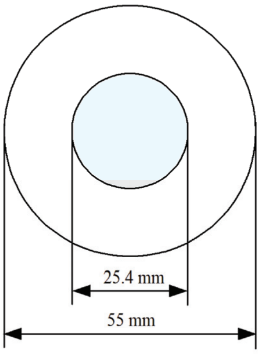

*Figure 1. Schematic of the sample collection process.*

### Physicochemical analysis

To determine water activity ($a_w$) of samples, a Testo 650 measuring instrument with a pressure-tight precision humidity probe was used (Testo AG, USA).

In order to determine weight loss five sausages from each batch were weighed just after stuffing (0 day). The same sausages were reweighed at previously mentioned periods of the process. The differences in weight are expressed as percentage of the initial weight.

Water and ash contents were quantified according to the ISO recommended standards 1442:1997 [8] and 936:1998 [9], respectively.

### Modeling drying kinetics

Average moisture content for thin layer drying is presented by the following expression:

$$M_R = (M - M_e) / (M_0 - M_e) \tag{1}$$

Since the value of the dynamic equilibrium moisture content $M_e$ (kg water/kg dry matter) is relatively small compared to $M$ or $M_0$, respectively, the dimensionless moisture ratio $M_R$ can be simplified to [10--12]:

$$M_R = M / M_0 \tag{2}$$

where $M$ and $M_0$ are the moisture content at any given time (kg water/kg dry matter) and the initial moisture content (kg water/kg dry matter), respectively. In order to determine the moisture content as a function of drying time, non-linear mathematical models in Table 1 were used by several authors [7,10-17] to describe the thin layer drying of various fruits, vegetables, olive pomace, algae and fish. Therefore, these models were attempted to study the drying kinetics of sausages ripened in different conditions. Most of them are exponentially decaying functions which describe the process of the moisture content decrease with time, appropriately. Only Wang and Singh model represents the second-degree polynomial equation relating moisture content and time, but according to the authors mentioned above, this model also gives good prediction of experimental data.

The adequacy of the models has been evaluated by the coefficient of determination ($r^2$), which should be close to one, root mean square error ($E_{RMS}$) and the reduced chi-square ($\chi^2$). The higher the values of $r^2$ and the lower the values of $E_{RMS}$ and $\chi^2$, the better is the goodness of fit. These parameters can be calculated as follows [14,18]:

$$E_{RMS} = \left[ (1/N) \sum_{i=1}^{N} \left( M_{R,\exp,i} - M_{R,\mathrm{pre},i} \right)^2 \right]^{1/2} \tag{3}$$

$$\chi^2 = \frac{\sum_{i=1}^{N} \left( M_{R,\exp,i} - M_{R,\mathrm{pre},i} \right)^2}{N - z} \tag{4}$$

where $M_{R,\exp,i}$ and $M_{R,\mathrm{pre},i}$ are experimental and predicted dimensionless moisture ratios, respectively, $N$ is number of observations and z is number of constants.

Statistical analysis was performed using Statistica 9.1 software (StatSoft, Tulsa, Oklahoma, USA).

## RESULTS AND DISCUSSION

### Weight loss, water activity, moisture and ash content

During ripening of *Petrovská klobása* considerable drying occurred. The changes in $a_w$ and weight loss along the ripening period showed the usual trends observed in this type of products (Figure 2). The weight loss of sausages averaged over the drying type was significantly higher for products ripened in the Industrial room compared with those ripened in a traditional room (47.71 *vs.* 42.71%, $p < 0.05$). The water activity $a_w$ diminished from initial values of around 0.95 to 0.82-0.85. These $a_w$ values were in agreement with those generally found for various traditional dry-fermented sausages [1, 2, 19, 20]. Hence, batch I sausages showed, comparatively, higher weight loss and lower $a_w$ values throughout period of drying and ripening. This trend was determined by the influence of thermo-hygrometric conditions in industrial room (10 °C and 75% RH).

Different environmental temperature, relative humidity and air velocity conditions used in the respective drying/ripening operations resulted in different intensity of interior water migration and evaporation from the surface of the product. Subdivision of sau-

*Table 1. Mathematical models considered to describe drying behaviour of Petrovská klobása ($M_R$ - moisture ratio; t - drying time (day); k, n, a and b - constants)*

| Model no. | Model name | Model |
|---|---|---|
| 1 | Newton | $M_R = \exp(-kt)$ |
| 2 | Page | $M_R = \exp(-kt^n)$ |
| 3 | Henderson and Pabis | $M_R = a\exp(-kt)$ |
| 4 | Logarithmic | $M_R = a\exp(-kt) + b$ |
| 5 | Wang and Singh | $M_R = 1 + at + bt^2$ |
| 6 | Approximation of diffusion | $M_R = a\exp(-kt) + (1 - a)\exp(-kbt)$ |
| 7 | Two-term exponential | $M_R = a\exp(-kt) + (1 - a)\exp(-kat)$ |

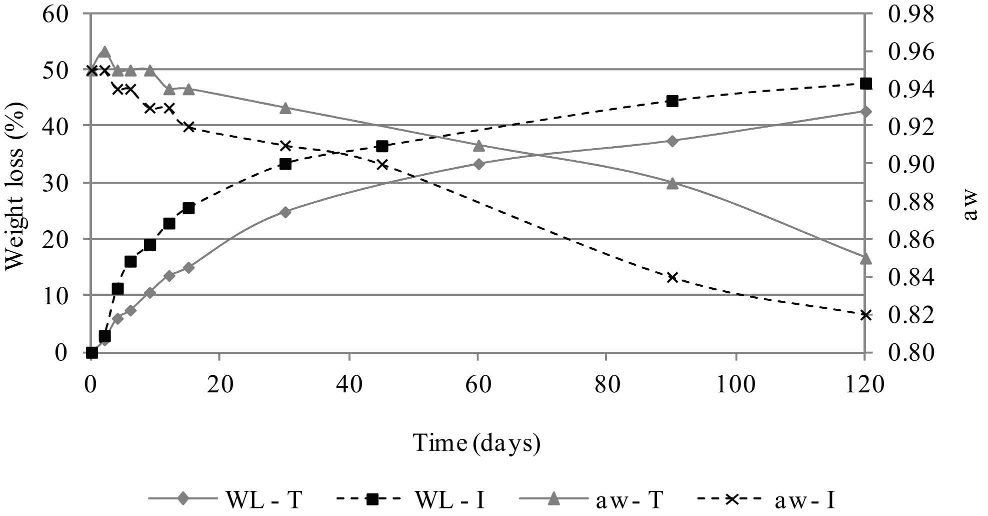

*Figure 2. Changes in weight losses (WL) and $a_w$ of Petrovská klobása during drying and ripening in traditional and industrial conditions.*

sage samples was necessary to investigate considerable difference between water and ash quantity in the various concentric fractions in relation to drying type and time.

Comparing the water content ratio and ash content ratio, among internal and external fractions, for both types of drying (Figure 3), some general observations can be made:

- the value for water content ratio is always higher than 1, which means that quantity of water is always higher in the internal fractions;

- the value for ash content ratio is higher than 1, except for first few days of industrial drying, which means that quantity of ash is in general higher in the internal fractions.

Hence, drying was much more marked in the external fractions and considerably lower in the internal ones. This was especially expressed throughout the first 30 days of drying in the industrial room when the water content ratio reached the highest value (1.71). Most probably, this was the consequence of the intensive water evaporation from the surface of the sausage caused by low RH and relatively high air velocity. It resulted in the formation of a thin peripheral ring. During the next 90 days absence of air circulation slowed down further evaporation. Due to the water concentration gradient between layers it continued migration from the center outward, and the water content ratio decreased to 1.15 after 120 days, indicating equalization of fractions in moisture quantity. On the contrary, drying in traditional conditions was slower and the water content ratio reached the highest value after 90 days (1.42), when it started gradual decrease.

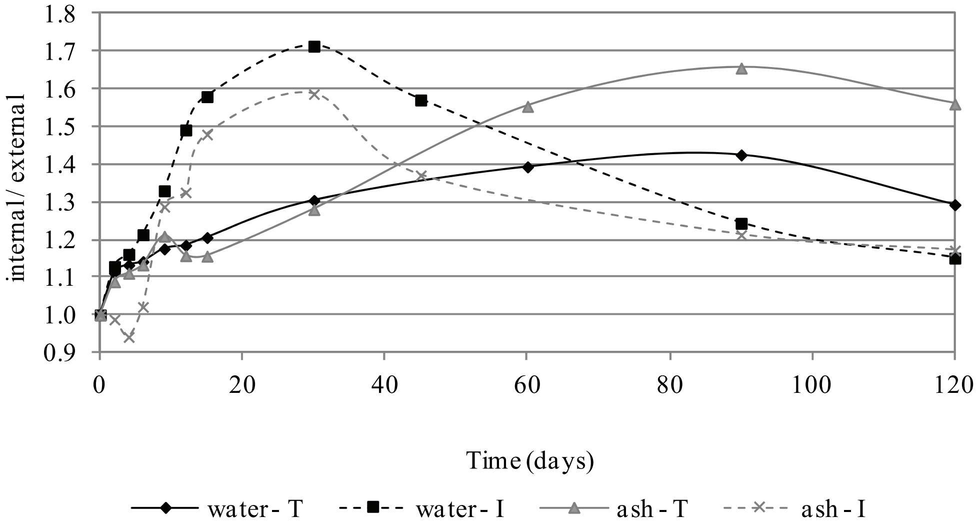

*Figure 3. Changes in moisture content ratio and ash content ratio between internal and external fractions of Petrovská klobása during drying and ripening in traditional and industrial conditions.*

Thus, as it can be seen, batch I sausages had almost equal moisture contents in different fractions after 120 days of ripening. This could lead to impression that these sausages had better drying characteristics, but it is not the case because they had very low absolute average moisture content, amounting 21.24%, *i.e.*, they were over-dried. On the other hand, after 120 days, batch T sausages had higher water content ratio but higher absolute water content also (32.77%). This water content is optimal for *Petrovská klobása*.

During drying of *Petrovská klobása* changes in ash content ratio showed the same pattern. Simultaneous, diffusion of water and dissolved substances occurred. The most important one is NaCl with opposite direction of diffusion in relation to water. As it makes approximately 65% of total ash in this sausage, migration of NaCl inwardly could be used to explain higher quantity of ash in internal part of sausages. These observations are in agreement with findings of various researchers [21,22].

## Model evaluation

The regression analysis was done for the seven thin layer drying models relating the drying time and dimensionless moisture ratio. The acceptability of the model is based on a value for the coefficient of determination ($r^2$) , the root mean square error ($E_{\mathrm{RMS}}$) and the reduced chi-square ($\chi^2$). Coefficient of determination is expressed as a value between zero and one. A value of one indicates a perfect fit, and therefore, a very reliable model for future forecasts. Values of root mean square error ($E_{\mathrm{RMS}}$) and the reduced chi-square ($\chi^2$) represent the differences between values predicted by a model and the values actually observed. The smaller the value of these parameters, the model better describes the obtained data. The values for the model coefficients and errors of statistical analysis are presented in Table 2.

The highest value for $r^2$ (0.990) was obtained by using the Page (No. 2) and the logarithmic regression model (No. 4) for describing traditional drying process (T), which indicates that 1% of the variations could not be explained by the model. However, it can be observed that the $E_{\mathrm{RMS}}$ and $\chi^2$ values of Page model ($2.22\times10^{-2}$ and $6.01\times10^{-4}$, respectively) are lower than the values obtained by the logarithmic model ($2.29\times10^{-2}$ and $7.22\times10^{-4}$, respectively). Furthermore, when comparing the model parameters for industrial drying process (I), it can be seen that the Page model (No. 2) and the approximation of the diffusion model (No. 6) have the highest value for $r^2$ as 0.995, which indicates that only 0.5% of variations could not be explained by the model. The lowest value for $E_{\mathrm{RMS}}$ of $1.74\times10^{-2}$ was obtained by using the approximation of the diffusion model. On the other hand, the Page regression model has the lowest value for $\chi^2$ of $3.91\times10^{-4}$. Therefore, the Page model proved to be adequate in both traditional and industrial conditions, so it was selected to represent the drying behaviour of *Petrovská klobása.* Experimental and predicted moisture contents have been plotted against time in Figure 4.

Obviously, there is a good agreement between experimental and predicted data, so this model can be used to estimate the moisture ratio of *Petrovská klobása* at any time during the drying process. This is of great importance for producers as the final quality of sausage depends markedly on moisture content.

*Table 2. Coefficients and errors of considered mathematical models determined through regression method for traditional (T) and industrial (I) drying of Petrovská klobása*

| Drying process | Model No. | Constants | $r^2$ | $E_{\mathrm{RMS}}\times10^2$ | $\chi^2\times10^3$ |
|---|---|---|---|---|---|
| T | 1 | $k = 0.0140$ | 0,899 | 7.18 | 5.67 |
| | 2 | $k = 0.0530$, $n = 0.6616$ | 0,990 | 2.22 | 0.601 |
| | 3 | $a = 0.9111$, $k = 0.0114$ | 0,964 | 4.29 | 2.25 |
| | 4 | $a = 0.6752$, $k = 0.0253$, $b = 0.2758$ | 0,990 | 2.29 | 0.722 |
| | 5 | $a = -0.0155$, $b = 0.0001$ | 0,944 | 5.37 | 3.52 |
| | 6 | $a = 0.2848$, $k = 0.0818$, $b = 0.0946$ | 0,983 | 2.98 | 1.22 |
| | 7 | $a = 0.1327$, $k = 0.0853$ | 0,957 | 4.71 | 2.71 |
| I | 1 | $k = 0.0274$ | 0,884 | 8.73 | 8.39 |
| | 2 | $k = 0.0926$, $n = 0.6227$ | 0,995 | 1.79 | 0.391 |
| | 3 | $a = 0.883$, $k = 0.0197$ | 0,942 | 6.20 | 4.69 |
| | 4 | $a = 0.7423$, $k = 0.004$, $b = 0.2009$ | 0,983 | 3.33 | 1.52 |
| | 5 | $a = -0.0216$, $b = 0.0001$ | 0,858 | 9.68 | 11.5 |
| | 6 | $a = 0.3751$, $k = 0.1249$, $b = 0.0897$ | 0,995 | 1.74 | 0.418 |
| | 7 | $a = 0.1662$, $k = 0.1229$ | 0,947 | 5.93 | 4.29 |

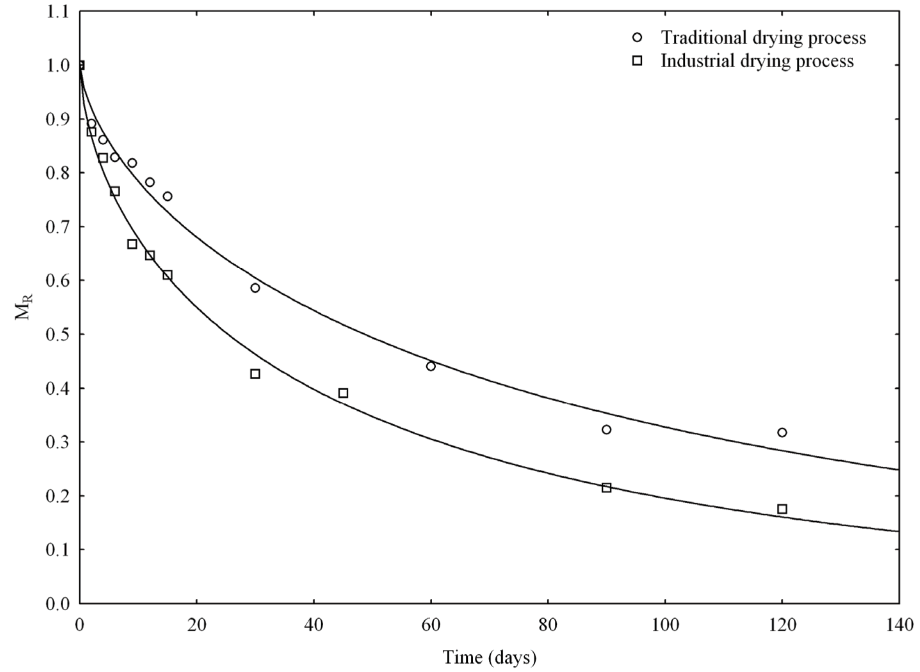

*Figure 4. Experimental and predicted moisture contents using the Page empirical model.*

Namely, simultaneously with drying, sausage undergoes different physical, microbiological and bio-chemical phenomena responsible for the appearance, flavour and aroma, as well as for its conservation and safety. The extent of these reactions is affected by moisture content.

As mentioned before, batch I sausages lost too much water during 120 days of drying in industrial chamber. In order to prevent this, the Page empirical model could be used to calculate the time needed to achieve optimal water content in *Petrovská klobása* (~ 32%), and in the same time to fulfill the requirements of Serbian legislation for this group of products [23]. The drying period, calculated using this model, lasts 60 days, which makes it twice as shorter comparing to traditional practice. This finding is very important from technological and economic point of view.

## CONCLUSIONS

Industrial drying of *Petrovská klobása* performed in this work resulted in sausages with different drying characteristics when compared to those counterparts from traditional production. These sausages had higher weight loss and lower $a_w$ values during the whole period of drying and ripening. Difference in drying intensity between various fractions was much more marked for sausages dried in industrial room.

The predicted and experimental values of moisture content show the suitability of the Page model in describing drying behaviour of *Petrovská klobása*, dried in both traditional and industrial conditions.

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NAUČNI RAD

# UTICAJ POSTUPKA PROIZVODNJE NA KINETIKU SUŠENJA TRADICIONALNE FERMENTISANE *PETROVAČKE KOBASICE*

*U radu su ispitane osobine Petrovačke kobasice (Petrovská klobása) tokom sušenja u tradicionalnim i industrijiskim uslovima proizvodnje. Dobijeni rezultati pokazuju da su kobasice sušene u industrijskoj komori (I) imale veći gubitak mase i niže vrednosti aktivnosti vode* ($a_w$) *u odnosu na one sušene u tradicionalnim uslovima (T). Takođe, razlika u intenzitetu sušenja između unutrašnjih i spoljašnjih frakcija je bila izraženija kod kobasica I. Eksperimentalni podaci za sadržaj vode u kobasicama upoređeni su sa vrednostima izračunatim pomoću sedam različitih matematičkih modela. Na osnovu vrednosti koeficienata determinacije* ($r^2$)*, korena srednje kvadratne greške* ($E_{RMS}$) *i hi-kvadrata* ($\chi^2$) *za svaki model zaključeno je da Page-ov matematički model na odgovarajući način opisuje karakteristike sušenja Petrovačke kobasice, kako u tradicionalnim* ($0,990$; $2,22\times10^{-2}$ *i* $6,01\times10^{-4}$, *redom), tako i u industrijskim uslovima proizvodnje*($0,995$; $1,79\times10^{-2}$; $3,91\times10^{-4}$, *redom).*

*Ključne reči: Petrovačka kobasica, uslovi sušenja, frakcije kobasice, matematički model.*