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Mathematical modelling and analysis of the mushroom drying process at the optimal temperature

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ABSTRACT
To preserve food is used drying method. It was found experimentally that drying mushroom caps and legs should be conducted at temperatures close to 52,5°C and 55,5°C, accordingly. In this case, we can get the product of the highest quality. Statistically, we proved that the drying processes of mushroom caps are different for fixed levels of temperature (from 40° C to 80° C, by step 10° C). At the same time, at higher temperatures, the nature of the process changes abruptly. Based on the experimental data, the polynomial regression model was built. This model can used for estimating and forecasting a specific evaporation heat at the optimal temperature.
***Keywords* –** drying process, humidity, mushroom, optimal temperature, polynomial model, specific evaporation heat

I. INTRODUCTION

There are many ways to preserve a food. One of the most important is the drying. It is important that products are harvested kept its taste and usefulness. For example, some problems of drying are studied in [1]. Mushrooms are the very delicious product, but contain only 10% of dry matter and the remaining 90% is water. Nutritional value of mushrooms bodies determined by the content of essential and conditionally essential amino acids: lysine, threonine, valine, leucine, isoleucine, tryptophan, cysteine, methionine, phenylalanine and tyrosine. The biological value of mushroom mycelium index is determined by essential amino acids, is ranged from 72,9-98,6 (according to EAA index). There are some limiting amino acids: methionine, tsystin, leucine, isoleucine. The biological value is 67,8-95,8 (according BV FAO). Amino acid index ranges 36,0-90,0. Index nutritional 22.2 (according to N FAO).

The fruit body chemical composition includes vitamins: thiamine (B1), riboflavin (B2), niacin (PP), pyridoxine (B6), biotin (H), ascorbic acid (C), folic acid (B9). The content of macro - and microelements that fully satisfy the needs of the human body provides the great value of fruiting bodies. Especially important and scarce micronutrients in mushrooms bodies consider the presence of selenium (Se).

Dried mushrooms are part of many delicious dishes. When the process parameters are chosen properly (drying temperature and final product humidity) a high quality products are achieved (nutrients are stored, they have a pleasant flavor and taste). The drying process is a heat and mass transfer phenomenon where water migrates from the interior of the drying product on to the surface from which it evaporates. In [2] was established there exist a significant difference between caps and legs of mushroom body. Drying processes of mushrooms legs are studied in [3].

II. MATERIALS AND METHODS

One of the modern methods for determining specific evaporation heat is a method of simultaneous thermal analysis (STA), which combines the calorimeter and thermo-grav analysis [4,5].

Laboratory facility DMKV-1 (Fig. 1, Fig. 2) was developed at the Institute of Technical Thermal Physics NAS Ukraine specially for this kind of research [6] and combines the functionality of calorimetry and thermogravimetry.

For experiments was used thin (about 1 mm thick) pileus tissue slices of the mushroom fruit body "Champignon". Drying of the samples was carried out at 40 ° C, 50 ° C, 60 ° C, 70 ° C, 80 ° C, air velocity of 0.8 cm / s and its initial moisture content of 8.5 g / kg. Registration of heat flows and changes in the mass of the sample drying process was carried out continuously. Drying specimens finished when they reach equilibrium moisture. The mass of dry matter was determined by final drying samples calorimeter at 105 ° C to constant weight.

Symbols:
r- specific evaporation heat, kJ / kg * K
t- time from the beginning to the end of the experiment, s
w - moisture,%
T- temperature, ° C

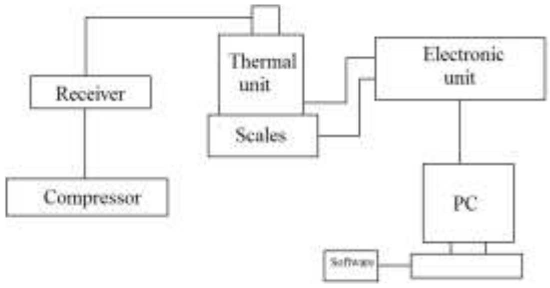

Fig. 1. Structural schema DMKV-1.

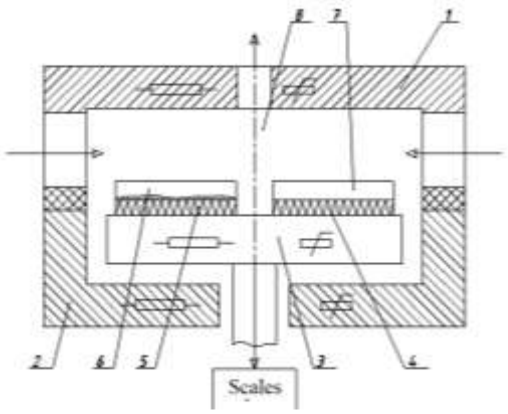

Fig. 2. Fundamental thermal unit schema DMKV-1.

1, 2 - top and bottom thermostatted blocks;
3 - calorimeter platform with the main electroheater;
4, 5 - heat flow meters;
6 - cell with the sample of research material;
7 - cell with the standard; 8 - working chamber.

III. RESULTS AND DISCUSSION

It was found experimentally that drying mushroom caps should be conducted at temperatures close to 52,5°C. In this case, we can get the product of the highest quality. Based on the data of the experiment it is important to build and explore the specific evaporation heat (r) dependence of humidity (w) at the optimum temperature $T_{opt} = 52.5$ for the constant pressure condition.

During the experiment, five temperature levels were fixed at 40° C, 50° C, 60° C, 70° C, 80°C. Accordingly, we have five different drying processes. A specific evaporation heat at a given level of humidity w, was measured for each process (Table 1). The null hypothesis is that the data for each drying temperature have identical distributions. Since, the amounts of samples small ($n = 9$) and there is no reason to believe that data is normally distributed, non-parametric tests were used (Wilcoxon test and sign-test). Both tests yielded similar results: the hypothesis is rejected at significance level $\alpha = 0,05$ for all pairs of variables, besides the pair of variables, which corresponds to the value of 60 ° C and 70 ° C, where type I error slightly higher. Thus, statistically, we also have to deal with five different processes.

We can assume that for adequate regression model, it is possible to make the conversion dependent variable:

$$w \mapsto \begin{cases} w^{\lambda}, & \lambda \neq 0 \\ \log w, & \lambda = 0 \end{cases}$$

by scatter diagram visualization in STATISTICA.

Using the program Boxtidwell, we estimate maximum likelihood parameter conversion λ and accordingly, it is desirable to consider transformation $w \mapsto w^2$. Even better results can be achieved by approximation using the polynomial regression as $y = b_0 + b_1 x + b_2 x^2$. A regression curve and its analytical appearance, 95% confidence interval (dotted line) is shown on each of the (Fig. 3-7). Quality of the models can be estimated on the Table 2.

As seen from Table 2, all of the coefficients b_0 and b_2 are significant at the level $\alpha = 0,05$, but the coefficient b_1 is not at 70°C. Therefore, the equation for 70° C is better to take without the appropriate member: $y = 2527,752 - 0,004x^2$, and estimation error will decrease from 3.59 to 3.43.

Since Fig. 7, we can see that the nature of the drying process changes dramatically. There is no sense to use the experimental data at 80°C, considering that $T_{opt} = 52.5$ (Table 3).

Then, using the results (Table 3) a linear dependence $b_0 = f0(T)$, $b_1 = f1(T)$ and $b_2 = f2(T)$ is build:

$b_0 = 2855,862 - 247,317 \cdot T$,

$T_{opt} = 52.5$, hence $b_0 = 2608,545$.

$b_1 = 6,423 - 4,628 \cdot T$,

$T_{opt} = 52.5$, hence $b_1 = 1,795$.

$b_2 = -0,111 + 0,076 \cdot T$,

$T_{opt} = 52.5$, hence $b_2 = -0,035$. Finally, the model is: $r = 2608,545 + 1,795w - 0,035w^2$, and the corresponding 95% confidence intervals for coefficients, are: $b_0 \in [2603,801;\ 2613,288]$, $b_1 \in [1,037,\ 2,552]$, $b_2 \in [-0,052;\ -0,017]$.

Table 1: observation data

w	**T=40°C**		**T=50°C**		**T=60°C**		**T=70°C**		**T=80°C**	
	№	***r***	**№**	***r***	**№**	***r***	**№**	***r***	**№**	***r***
90	1	2462,00632	10	2500,27542	19	2421,51408	28	2486,82968	37	2497,86484
80	2	2594,44269	11	2574,30108	20	2472,96711	29	2504,08285	38	2498,1502
70	3	2613,68588	12	2605,46985	21	2513,30813	30	2509,72037	39	2490,06305
60	4	2652,21084	13	2616,01081	22	2539,48108	31	2514,26749	40	2499,64728
50	5	2664,11301	14	2626,14557	23	2553,54145	32	2516,70095	41	2499,80394
40	6	2677,59847	15	2647,04263	24	2570,54635	33	2517,43496	42	2500,39347
30	7	2689,49413	16	2648,88333	25	2576,40635	34	2522,34935	43	2501,35014
20	8	2698,80949	17	2650,12242	26	2586,75565	35	2524,93564	44	2506,25214
15	9	2714,35886	18	2650,77995	27	2589,05379	36	2528,43252	45	2509,20498

Table 2: quality of the models

Model	R^2	*p*-value b_0	*p*-value b_1	*p*-value b_2	Residuals normality
40°C	0,925	0,000	0,150	0,017	yes
50°C	0,954	0,000	0,035	0,003	yes
60°C	0,992	0,000	0,012	0,000	yes
70°C	0,938	0,000	0,560	0,046	yes
80°C	0,920	0,000	0,005	0,018	yes

Table 3: estimations of the coefficients

Model	b_0	b_1	b_2
40°C	2668,3331	2,6648	-0,0510
50°C	2620,1616	2,2275	-0,0376
60°C	2570,8244	1,4056	-0,0333
70°C	2527,7520	0	-0,0040

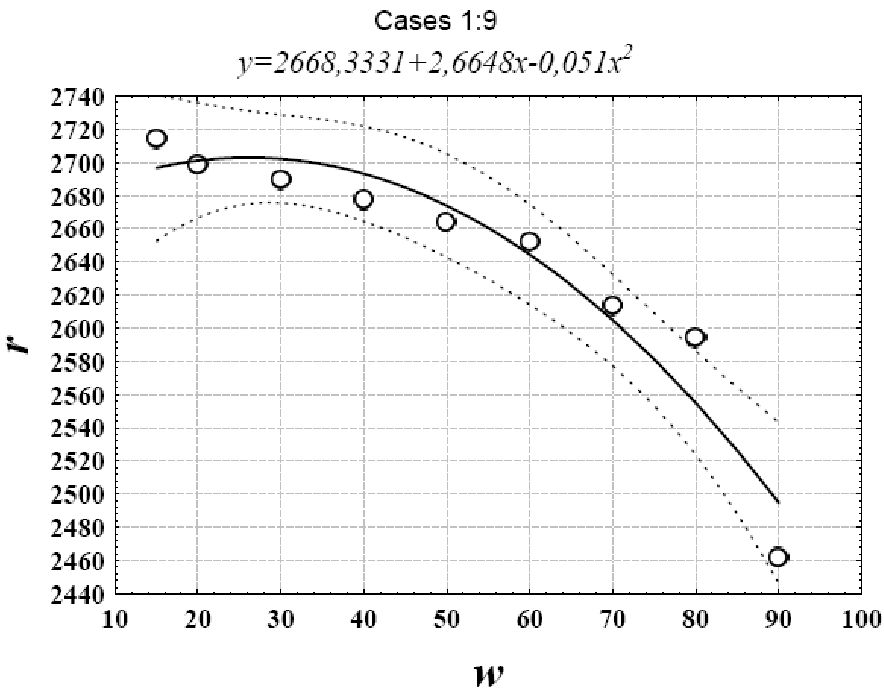

Fig. 3: Drying at 40°C

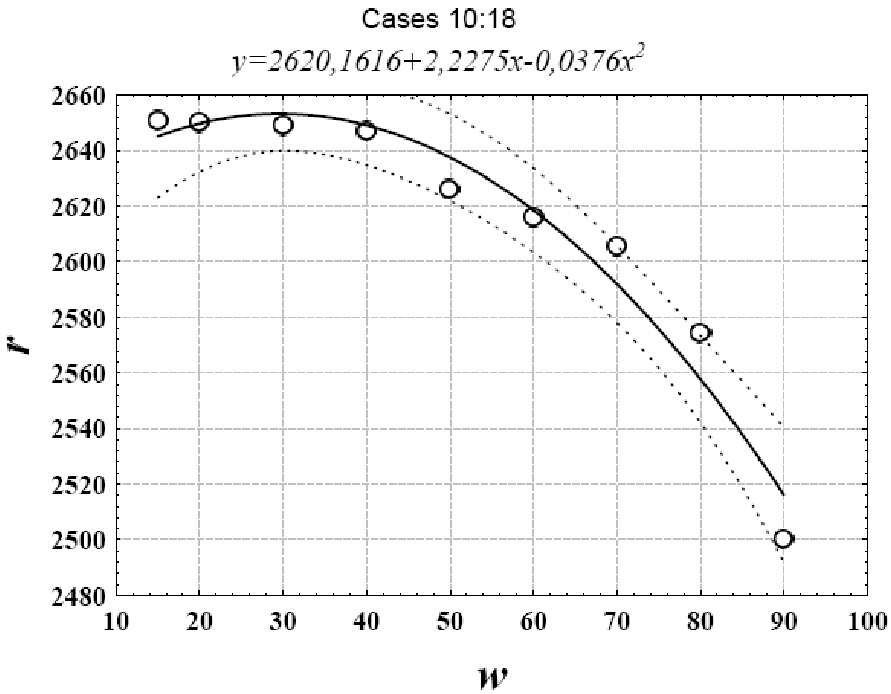

Fig. 4: Drying at 50°C

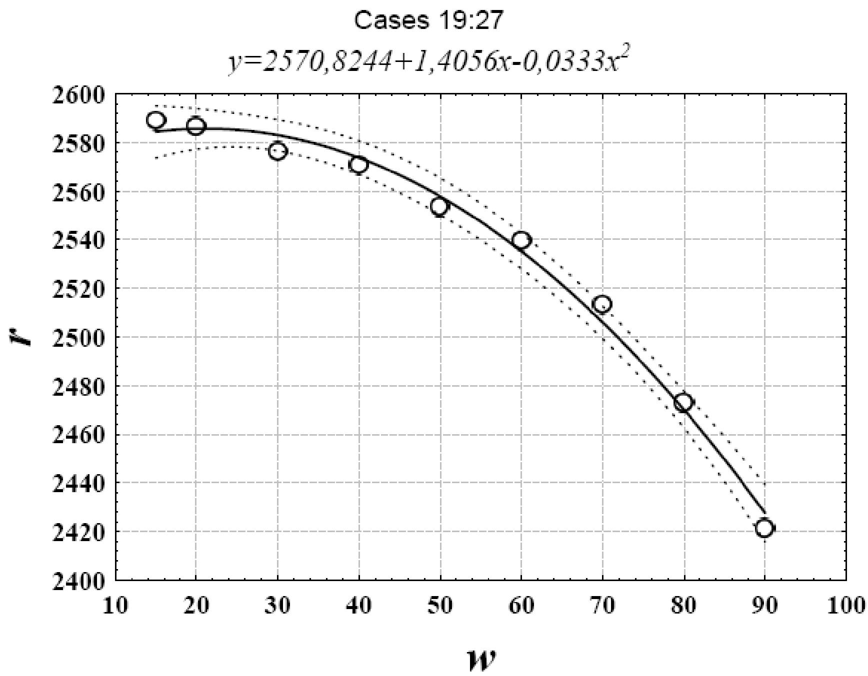

Fig. 5: Drying at 60°C

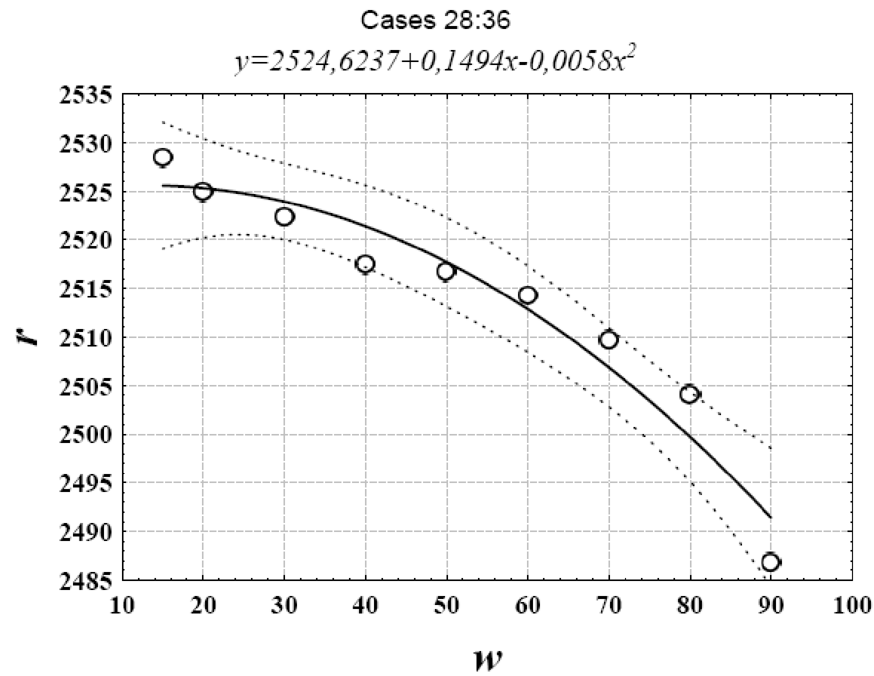

Fig. 6: Drying at 70°C

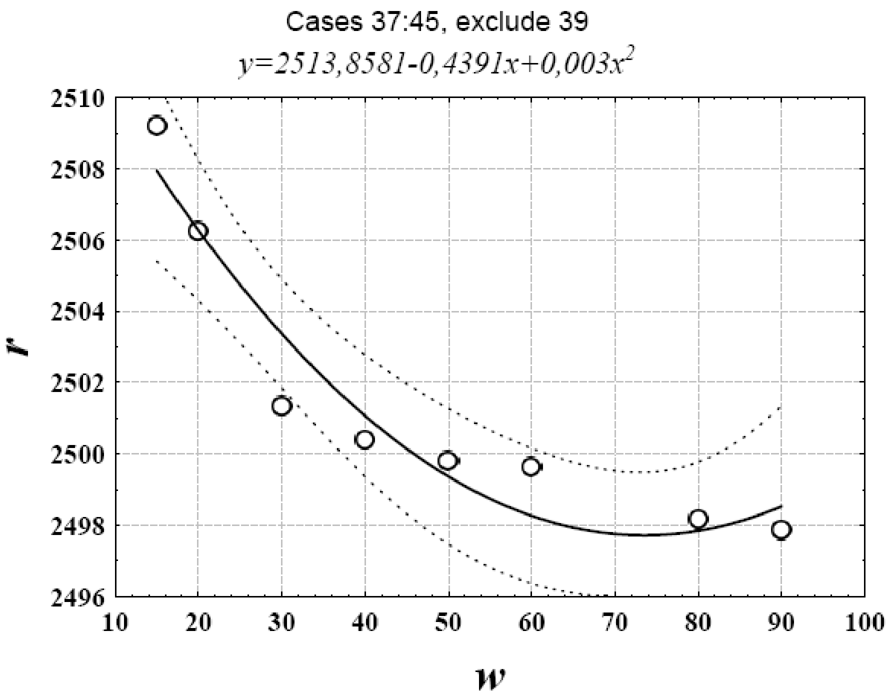

Fig. 7: Drying at 80°C

IV. CONCLUSION

The results obtained in this paper allow one to see the drying behaviour of mushrooms caps in case of five fixed levels. Statistically proved, that we have a sample from a mixture of distributions. We built the polynomial regression for each temperature level. Furthermore, using the regression coefficients, we build the estimator for specific evaporation heat in case the optimal temperature. All equations holds under constant pressure condition. This is another important step to solving the problem of effective drying process for mushrooms. Future research will be devoted to the simulation drying processes with an arbitrary pressure.

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