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THE INFLUENCE OF TEMPERATURE OF FREEZE-DRYING PROCESS ON THE MECHANICAL PROPERTIES OF DRIED MUSHROOMS

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ABSTRACT

Some mechanical properties of fresh and freeze-dried mushrooms have been described. Modulus of elasticity was determined from the squeezing tests. The set quantities have been related to the heating plate temperature and density of samples. The obtained relationships have been approximated with exponential functions.

Key words: mechanical properties, mushroom, freeze-drying, modulus of elasticity

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INTRODUCTION

Freeze-drying process is a modern way of preservation of food and biological material. The products preserved by the method feature with relatively low quality deterioration (smell, taste, colour, chemical composition) when compared with the fresh product. Such behaviour follows from the fact that the material is dried at low temperature, under significantly reduced pressure in a drying chamber, assuring sterility of the process [5, 4]. The dried product is usually directed to the storage houses, what demands for appropriate durability and mechanical resistance. Therefore, the improvement of freeze-drying process is strictly connected with the recognition of the relations between the process parameters and mechanical properties of resulted dried material.

A great number of the latest contributions concerns the problem of establishing the influence of different drying methods, including the freeze-drying, on the mechanical and rheological properties of the products subjected to rehydration [1, 6, 3]. The investigations aim at determining the reconstruction ability of rehydrated dried material and the usefulness of the product as a component of instant food. However, there is a lack of information about the effect of drying conditions on the properties of dried material, subjected to the outer forces actions. Any contributions connecting the quality of dried material with its mechanical properties have not been presented yet.

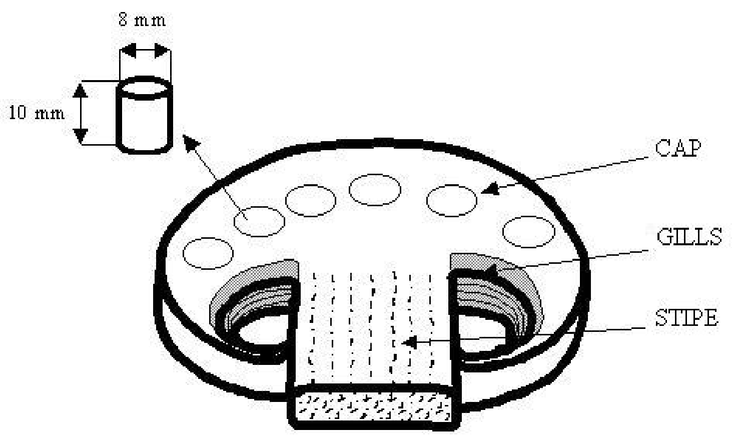
The aim of the work was to establish the influence of heating plate temperature during the freeze-drying process on the changes in the properties of dried material.

MATERIALS AND METHODS

The mushrooms (*Agaricus bisporus*) of kremowa variety were the object of examination. The choice of the variety resulted from its economical meaning, common availability and good drying properties. The fresh material was collected at the developing stage, at closed caps with the diameters from 50 mm to 70 mm. The samples were taken from the part of the cap with possibly homogenous cellular structure.

The samples for experimental studies were cut in cylindrical shapes, 8 mm x 10 mm, from the part of the cap which featured with little diversification in terms of structure orientation and cellular construction (Fig. 1).

Fig. 1 The way and site of sample collection.



Then, the collected sample of material was frozen in a freezing chamber with the rate of 1°C/min, down to the temperature of –25°C and freeze-dried. The freeze-drying process was carried out in a testing plant which enabled the change of many process parameters, among the other the heating plate temperature. Measurement of mass loss and temperature

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distribution inside the sample was possible [2]. The drying was conducted with radiation heating of material by the heating plate at the temperatures of 0°C, 30°C, 70°C and 100^{o}C, under the pressure of 25 Pa in the drying chamber. The process was interrupted when the water content inside the dried samples approached the value of 0.1 kg H_2O/kg d.m. The sample temperature at the final stage of drying process ranged from 0°C, for the 0 °C heating plate temperature, to 40–45°C for 100°C temperature of the heating plate.

Mechanical tests were performed on Instron 5566 stress testing machine. The tests of uniaxial squeezing were carried out in quasi-static conditions at the rate of measuring beam shift of 0.5 mm/min, at the ambient temperature of + 18C. For the measurements, the measuring heads with the ranges of 100 N (at accuracy of ±0.1%0 and 1000 N (at accuracy of ± 0.5%) were used. The samples of material - fresh and freeze dried at four values of heating plate temperatures, were subjected to squeezing tests. Each measurement was repeated for 15 times. As the result, the values of elasticity modulus E', defined as the ratio of maximum stress - σmax to strain -ε developed in effect of these stress, in the rectilinear range of stress-strain curve, have been estimated. The elasticity modules were calculated from the equation (1).

$$E' = \frac{\sigma_{max}}{\varepsilon}[\text{MPa}] \quad (1)$$

where;

$\sigma_{max} = \frac{4 \cdot F_{max}}{\pi \cdot d^2}$ – maximum stress [MPa],

F_{max} – maximum force [N],
d – diameter of sample [mm],

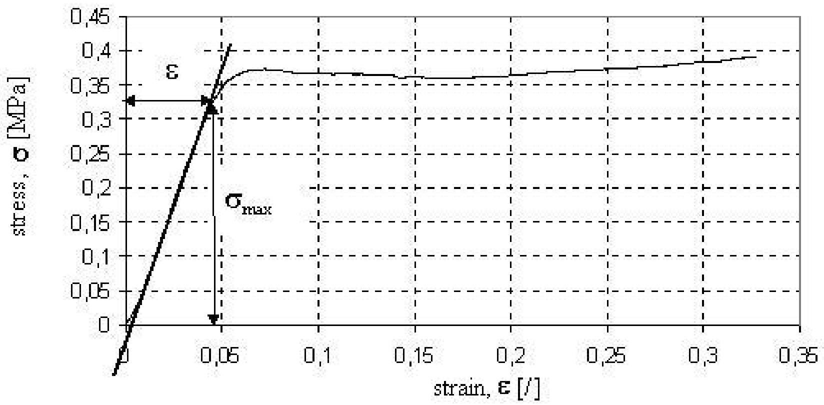
$\varepsilon = \frac{\Delta l}{l}$ – relative strain [/],

Δl – unrelative strain [\],

l – high of sample [mm],

Fig. 2 presents the way of determining the elasticity modulus for an exemplary run of the squeezing test (the sample produced at the heating plate temperature of 100°C) from the stress-strain curve.

Fig. 2. The way of determining the elasticity modulus.



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RESULTS AND DISCUSSION

Results of the squeezing tests for the samples of fresh and freeze-dried mushrooms, at different temperatures of the heating plate, have been shown in Figs. 3, 4A and 4 B.

Fig. 3 Stress - σ versus strain -ε curve for fresh mushrooms.

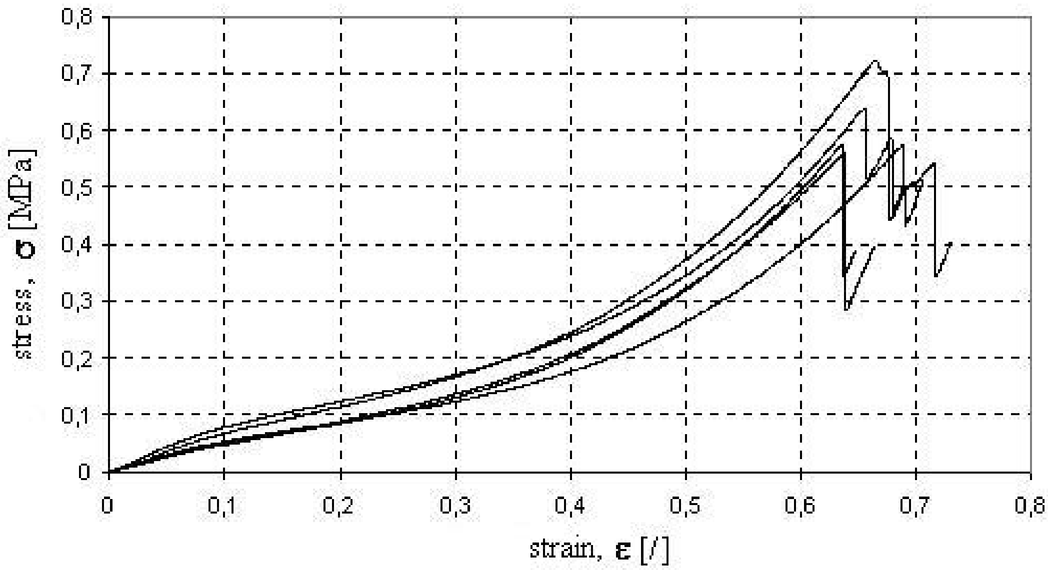
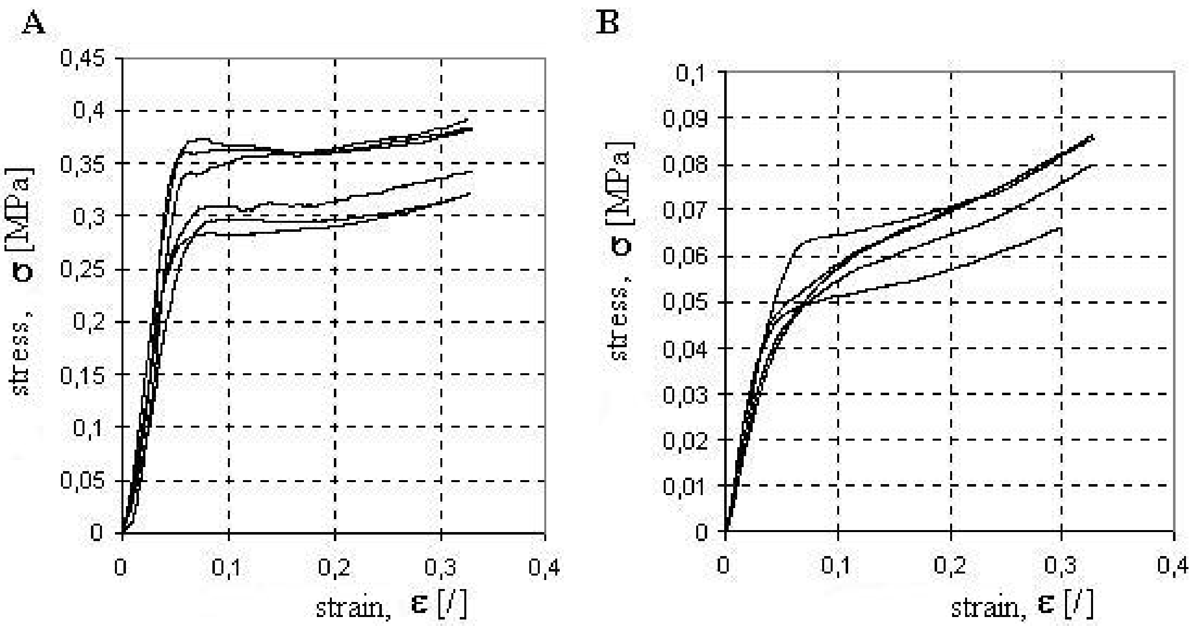


Fig. 4. Change in stress - σ versus strain - ε for freeze-dried samples at the temperature of heating plate of 100 °C (A) and 0 °C (B).



From the analysis of the dependencies shown in Figs. 3, 4 A and B it is apparent that the highest stress in the fresh material occurs for the relative strain of 0.6 – 0.7 whereas in the dried samples the maximum stress is achieved at the strain values of ca. 0.05. It means that

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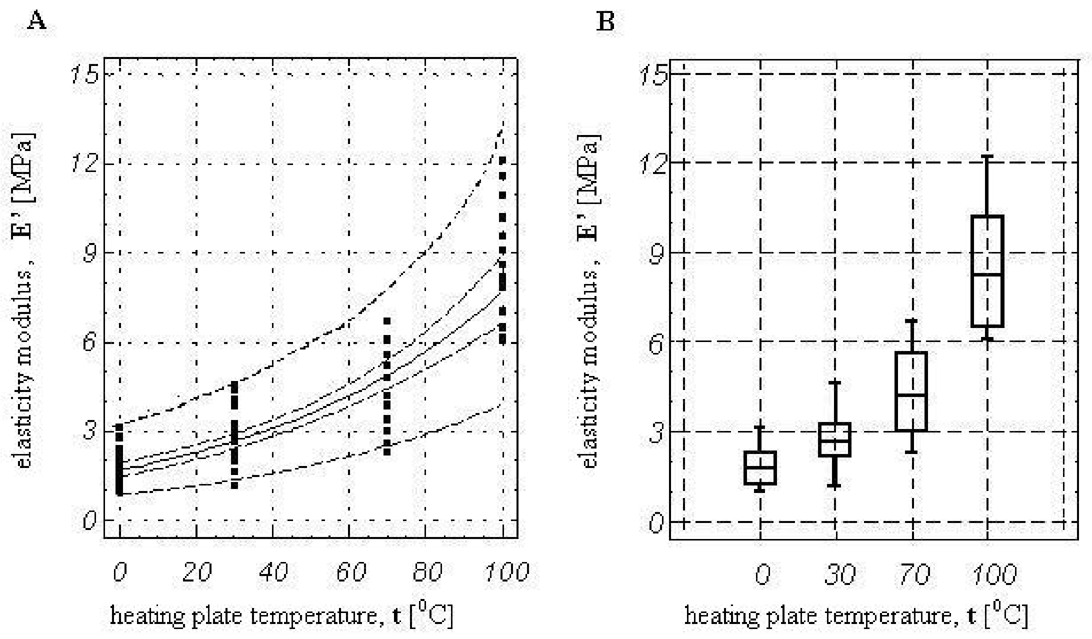
the freeze-dried material has much higher resistance to squeezing than the fresh one, what additionally finds the confirmation in the elasticity modulus values. The run of the stress – strain curve for the fresh material features with the coincidence of the point of biological resistance of the material with the highest stress. After exceeding the threshold, destruction of cellular structure takes place. The freeze-dried samples, after reaching the highest stress value, keep approximately constant value of strain, what is characteristic for material flow rage. Further progress of the process results in the swelling of the samples.

Fig. 5 shows the plot of the elasticity modulus versus temperature of heating plate for the samples frozen at the rate of 1C/min and dried in the drying chamber under the pressure of 25 Pa. The run of the plot indicates that the increase of drying temperature causes the increase in the immediate resistance of the material. The character of the change can be approximated with and exponential function,

$$\mathbf{E}' = 1.96 \cdot \exp(0.0177 \cdot \mathbf{t}) \quad (2)$$

where: 1.96 and 0.0177 – constanses of equation (2), [\],
The determination coefficient for the function is $R^2 = 0.7642$.

Fig. 5. The plot of changes in elasticity modulus values versus temperature of heating plate for the samples of freeze-dried mushrooms (A). Results of variance analysis of the effect of heating plate temperature on the elasticity modulus (B).



To confirm the influence of drying temperature on the value of elasticity modulus, the obtained results have been subjected to statistical processing with the Statgraphics plus 6.0. Results of variance analysis (table 1) show that the temperature of heating plate has some effect on the values of elasticity modulus of freeze-dried samples of mushrooms, at the significance level of 0.000. The uniformity has been also performed. Its results confirm the occurrence of statistical differences in elasticity modulus for different drying temperatures.

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Table 1. Results of variance analysis of the effect of heating plate temperature on the elasticity modulus.

Temperatures of the heating plate	Elasticty modulus average	Standard error	Confidence interval for average (95%)		Significance level
0°C	1.8248	0.3465	1.1299	2.5197	0.000756
30°C	2.8309	0.3254	2.1782	3.4836	0.000823
70°C	4.3482	0.4046	3.5367	5.1596	0.000156
100°C	8.5806	0.3465	7.8858	9.2755	0.000053

The repeatability of measurements is differentiated and can be characterized with the confidence interval from 2 MPa to 7 MPa (Fig. 5A). This indicates significant differences in elasticity modules for the same temperatures of heating plate. The observation suggests the presumption about the influence of additional significant factor on the change of the value of elasticity modulus. A hypothesis has been made that such big spread in the values of elasticity modulus result from the differences in density of dried material. The plot of elasticity modulus versus the density of dried material, resulting from the site where the sample was collected (differences in density in the range of mushroom cap), has been shown in Fig. 6. The dependence of elasticity modulus versus the density of dried samples (changing in the range from 70 to 105 kg/m^3), for different drying temperatures can be also fitted with exponential function,

$$E' = a \cdot \exp(b \cdot \rho) \quad (3)$$

The set of a and b constants from equation (3) and determination coefficients, have been shown in Table 2.

Fig. 6. The plot of the changes in elasticity modulus versus the density of dried material for different drying temperatures.

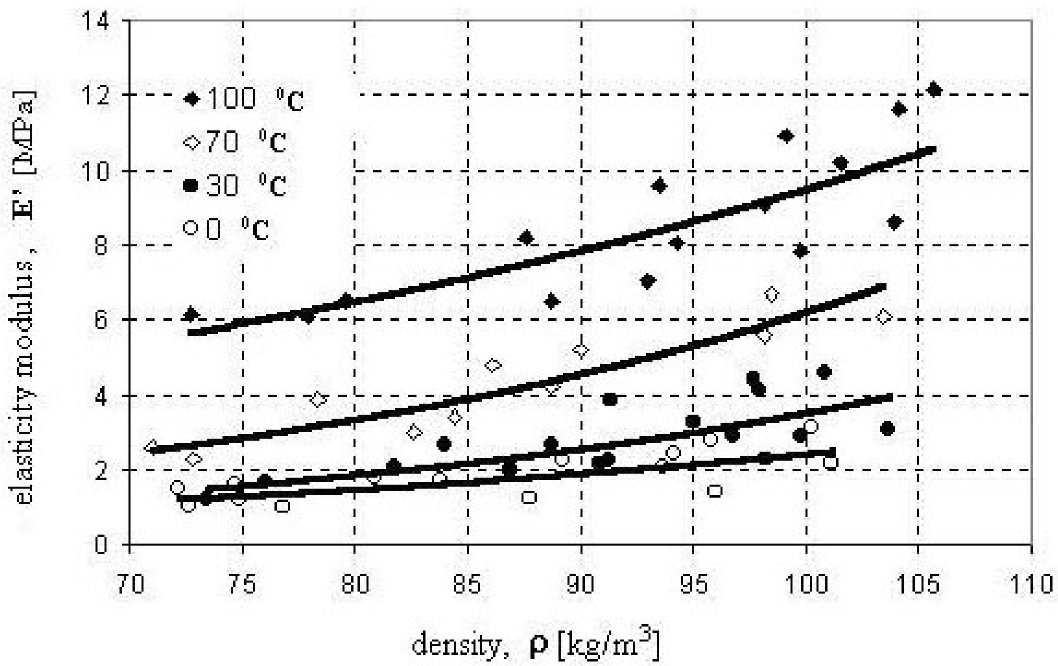

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Table 2. Coefficients of the equation E'= a · exp (b · ρ).

size	temperatures of the heating plate. **t** [°C]			
	0	30	70	100
a	0.2031	0.1427	0.2548	1.4266
b	0.0248	0.032	0.0317	0.019
R^2	0.5413	0.6138	0.8162	0.7078

The plots of elasticity modules versus material density for different temperatures, run quite regularly but become more and more steep with the increase in the temperature of heating plate. The dependence of elasticity modulus on density, and thus porosity of the material can be explained by the direct connection between the structure of dried material and its mechanical properties.

CONCLUSIONS

1. High value of maximum stress in the fresh mushrooms (ca. 0.5–0.7 MPa) undergoes high reduction in effect of freeze-drying process (to the value of ca. 0.05–0.4 MPa).
2. The freeze- dried material preserves approximately constant stress value in a wide strain range.
3. The hypothesis has been confirmed that the value of elasticity modulus of dried material depends not only on the drying temperature but also on the density of the sample. This in turn depends on the site of collection. The fact confirms the strong connection between the structure of dried material and its mechanical properties.

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