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SELECTED ASPECTS OF FREEZE-DRYING IN THE PRODUCTION OF INSTANTLY RECONSTITUTABLE FOODSTUFFS

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Abstract. The rehydration, compression, and cutting of garlic, mushrooms and celery from dried material prepared by the 'freeze-dry' method were analysed. The freeze-drying process was carried out at a pressure of 25 Pa and the temperature of heating plate ranging between 0-40°C. The rehydration of the dried material was carried out at a temperature of 95°C for between 3 minutes to 120 minutes. It was stated that the rehydration could be described by the Peleg's equation. It was found that freeze-drying caused a strong increase in compression but the time required for storage stabilises this parameter. It was also found that the effort required to cut the material increases as a result of the freeze-drying process and during storage.

Keywords: freeze-drying, rehydration, mechanical properties

INTRODUCTION

The majority of dried products are consumed or are subjected to further treatment after being rehydrated. Rapid rehydration is therefore an important consideration in handling instantly reconstitutable food. However, this advantage should be combined with the preservation of the smell and flavour as well as the reproduction of the mechanical properties of the rehydrated food, which qualities are both demanded by the consumer. The preservation of the flavour and smell relies on delaying or inhibiting the biochemical reactions which occur during the drying process. 'Freeze-drying' and more recently 'microwave drying' under reduced pressure are considered particularly advantageous for these purposes. The problem is widely discussed in the literature and is the subject of numerous contributions [2,5,8].

A diffusion model, based on Fick's second law, with the assumption that the diffusion coefficient depends exclusively on temperature [1,10] is commonly used to describe the rehydration of dried vegetable material.

Empirical models are also very popular, which not only avoid the large complexity of Fick's model but also its excessive simplicity, such as the constancy of the dimensions during rehydration. The more popular is Peleg's model [4], which has been used in the simulation of the rehydration process of convection dried apples, celery and carrot [9] and in the rehydration of freeze-dried celery, carrot and parsley [3]. A number of papers containing information on the mechanical characteristics of dried material, mostly after rehydration, have been published in the literature over the last few years [3,6,7]. Information about rehydration combined with the mechanical characteristics of rehydrated dried material seems to be very important in the development of guidelines for the preparation of instantly reconstitutable food.

MATERIALS AND METHODS

Samples of the most common varieties of garlic, mushroom and celery on the Polish market (such as the 'Kremowa' variety of mushroom) were used in the experiments. The vegetables intended for rehydration tests were cut into cubes, the sides of which measured 8 mm. For the mechanical tests, the celery and the mushrooms were cut into cubes whose sides measured 8 mm whereas the garlic cubes measured 5 mm. The freezing was carried out in a typical refrigerator at a temperature of $-27^{o}C$, where the material was stored for 24 hours. Freeze-drying was conducted at a pressure of 25 Pa and the temperature of heating plate ranging from $0^{o}C$ to $40^{o}C$. The heat was supplied in contact mode. A complete description of the laboratory stand applied in the freeze-drying process is presented in paper [3]. Rehydration was carried out in water at a temperature of $95^{o}C$ for between 3 minutes to 120 minutes. During rehydration, the dry mass content was determined according to PN-90/A-75101 and PN-90/A-75631 for the celery and garlic, respectively.

The mechanical characteristics were tested with the 'Instron 5566' strength testing machine with replaceable heads and a stress range from 100 N to 1 kN. The measurement details and the method of determining the compression and effort required to cut the material are given in paper [3]. A statistical analysis of the effect of the heating plate temperature and the storage time on selected mechanical characteristics of the dried material was carried out using STATISTICA software. Variances in the sub-groups were heterogeneous. For this reason, a two-way variance was not applied (the Bartlett test). Where the 'variance homogeneity' condition was fulfilled, the 'one-way variance' analysis was applied. Where the condition was not fulfilled, the 't-Student' test was applied to compare the averages of the two populations in the case of the equal variance of the populations, and the 'Cohran-Cox' test in the case of the inequality of the two variances.

RESULTS AND DISCUSSION

The kinetics of the rehydration of the materials examined is shown in figure 1. The graphs also show the runs approximated by the Peleg's model [4]:

$$M = M_0 + \frac{t}{K_1 + K_2 \cdot t} \tag{1}$$

where: M – water content, kg(kg d.s.)$^{-1}$,
M_0 – initial water content, kg(kg d.s.)$^{-1}$,
K_1 – Peleg's coefficient 1, [kg(kg i.d.s.)$^{-1}$] s^{-1},
K_2 – Peleg's coefficient 2, kg(kg i.d.s.)$^{-1}$,
t – time, s.

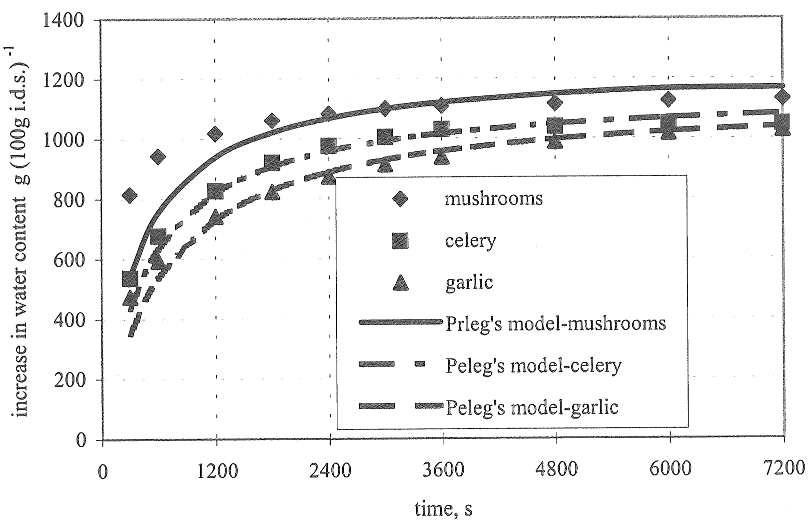

Fig. 1. Rehydration kinetics of the investigated materials described with Peleg's model

The values of constant K_1 and K_2, estimated for the materials examined, are shown in table 1. The satisfactory approximation of the experimental results with the results of simulation has been confirmed by statistical analysis. Such coincidence has also been obtained in the rehydration of the freeze-dried celery, carrot and parsley [3] and in the rehydration of the convection dried apple, carrot and potato, however some discrepancies in Peleg's model were observed in the case of the carrot [10].

Table 1. Values of K_1 and K_2 constants in Peleg's equation

Product	K_1 [kg/(kg i.d.s.)$^{-1}$]s^{-1}	K_2 kg(kg i.d.s.)$^{-1}$
Garlic	0.59	$8.8 \cdot 10^{-4}$
Mushroom	0.31	$8.1 \cdot 10^{-4}$
Celery	0.42	$8.6 \cdot 10^{-4}$

An analysis of the rehydration results for freeze-dried root vegetables has shown that the process can be described with satisfactory accuracy using Fick's equations. This is especially the case for studies on celery rehydration [1].

Figure 2 shows the measurement results of the compression of garlic for different storage times and different heating plate temperatures. The compression work of the material subjected to freeze-drying and rehydration is significantly lower than those for the raw material. However, the compression values decrease very slowly with storage. Similar relationships have been observed in the case of the mushroom and celery. The temperature of the heating plate has little effect on the value of the compression of the rehydrated dried material, directly after freeze-drying. For material stored for some period of time, the effect of the temperature of the heating plate on the value of this parameter was statistically insignificant.

Figure 3 shows the values of the cutting of the garlic at a heating plate temperature of 40^{o}C. Freeze-drying causes an increase in the work required for cutting the rehydrated material in comparison with the raw material. The storage of the material resulted in a further increase in the effort required for cutting. The relationship has been approximated with an exponential curve (determination coefficient $R^2 = 0.998$). The character of change in cutting versus the heating plate temperature and the storage time of the dried material in the case of the mushrooms was much more complex (fig. 4). A significant effect of the temperature of the heating plate on the effort required for cutting was observed after one year in storage. An increase in heating plate temperature results in a decrease in the effort required for cutting, but only at 40^{o}C does any statistically significant difference between the product and raw material occur.

The cutting of the celery versus the storage time of the dried material and the heating plate temperature is similar to garlic (fig. 5). Prolonged storage causes a significant increase in the value of this parameter, but the effect of the heating plate temperature is not important.

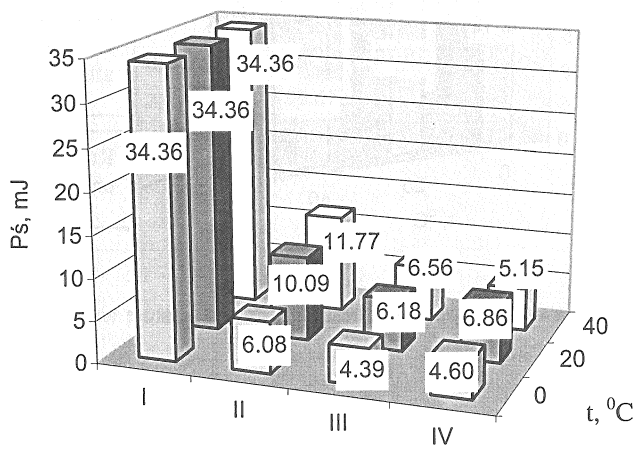

Fig. 2. Average garlic compression values (Pś) versus the storage time of the dried material (I – raw material, II – rehydration directly after freeze-drying, III – rehydration after one year storage, IV – rehydration after two years storage) and temperature of heating plate

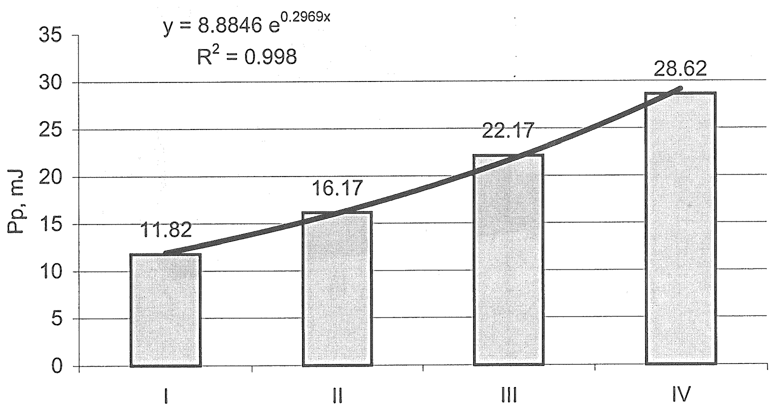

Fig. 3. Garlic cutting values (Pp) versus the storage time of the dried material (I – raw material, II – rehydration directly after freeze-drying, III – rehydration after one year storage, IV – rehydration after two years storage) at heating plate temperature of 40 ^{0}C.

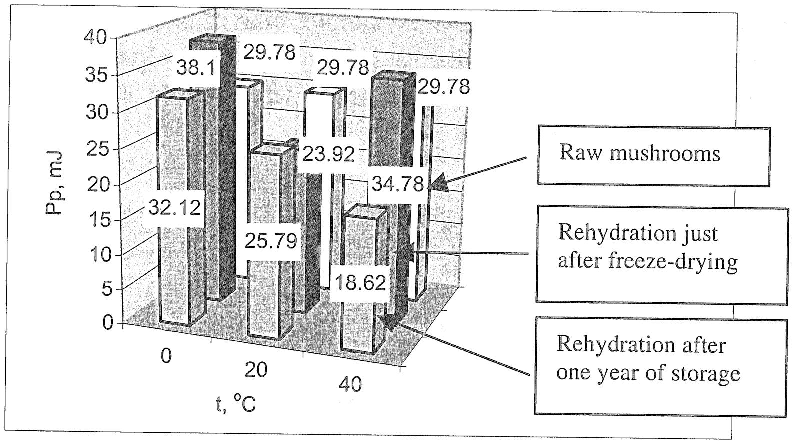

Fig. 4. Average cutting values (Pp) versus heating plate temperature and storage time of rehydrated freeze-dried mushrooms

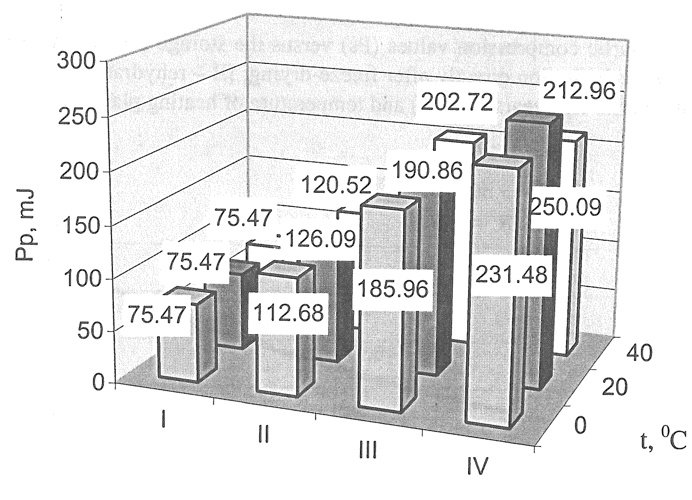

Fig. 5. Cutting values for (Pp) celery versus the storage time of the dried material (I – raw material, II – rehydration directly after freeze-drying, III – rehydration after one year storage, IV – rehydration after two years storage) and temperature of heating plate

CONCLUSIONS

1. The rehydration of tested freeze-dried materials can be approximated by the Peleg's empirical model.

2. The value of compression of the rehydrated material is lower than that of the raw material and decreases with the storage time.

3. The effort required to cut up the celery and garlic after rehydration of the freeze-dried material increases with the storage time. In the temperature range tested, the temperature of the heating plate does not have any significant effect on the effort required for cutting the material.

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WYBRANE ASPEKTY SUBLIMACYJNEGO SUSZENIA PRZY WYTWARZANIU ŻYWNOŚCI SZYBKOODTWARZALNEJ

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S t r e s z c z e n i e. Analizowano rehydrację, pracę ściskania oraz pracę przecinania suszu z czosnku, pieczarek i selera uzyskanych metodą sublimacyjną. Suszenie sublimacyjne prowadzono pod ciśnieniem 25 Pa w zakresie temperatur płyty grzejnej od 0°C do 40°C. Rehydrację suszu prowadzono w temperaturze wody równej 95°C w czasie od 3 do 120 minut. Stwierdzono, że rehydracja przebiega zgodnie z modelem Pelega. Sublimacyjne suszenie powoduje gwałtowny spadek wartości pracy ściskania, natomiast w czasie dłuższego przechowywania następuje stabilizacja tego parametru. Wartość pracy przecinania wzrasta na skutek suszenia sublimacyjnego. W trakcie przechowywania następuje jej dalszy wzrost.

S ł o w a k l u c z o w e: suszenie sublimacyjne, rehydracja, właściwości mechaniczne