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Influence of heating plates temperature on freeze drying energy requirements and quality of dried vegetables

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Summary. The paper presents the results of research concerning the influence of heating plates temperature of freeze dryer (40, 50, 60, 70°C) on specific drying energy and selected properties of dried vegetables (celery, parsley, carrot). The results showed that an increase of heating plates temperature caused a decrease a specific drying energy (average about 60%), but rehydartion ability and L-ascorbic acid content also decreased. The highest changes of this acid were observed when temperature increased from 60 to 70°C. The optimum temperature during freeze drying process of investigated vegetables was 60°C.

Key words: lophylization, drying, specific energy, quality, vegetables.

INTRODUCTION

Freeze drying of foods is one of the best methods of water removal which results in the highest quality of final product. The freeze drying process was first used to food products after the Second World War, in order to preserve and store foods without the refrigeration. Vegetables, fruits, fish, meats, dairy products, herbs and food flavourings can be successfully lyophilized [10,14]. Low temperature during freeze-drying stops microbiological activity and thus the quality of the final product is better. Another important advantage is that during this process the various heat-sensitive biological compounds are not damaged [8,9]. This process retains the physical structure of the food product and preserves it for re-hydration at a later date. It is generally accepted that the flavor of freeze dried foods is better than the air dehydrated products [16,19,21]. However due to the process-specific mechanisms, time of drying and the costs of system is viewed as one of the most energy-consuming food preservation methods [3,12,18]. Thus generally the use of freeze drying in the food industry is limited.

The sublimation rate is the mass of ice sublimed (kg) per unit time (s), which can be expressed [17]:

$$\frac{dm}{dt} = \frac{P_{ice} - P_c}{R_p + R_s}, \qquad (1)$$

where: dm/dt is ice sublimation rate (kg/s), P_{ice} is the equilibrium vapor pressure of ice at the sublimation interface temperature (Pa), and R_p and R_s are the dry layer and stopper resistance, respectively, to water vapor transport from the sublimation interface (Pa·s·kg^{-1}).

Iturria et al [7] have given the formula (2) for calculation the total energy for frozen drying process of biological material. In the formula (2) Q_{total} is the total heat transferred to the sample (J), T_{sample} is the sample temperature (K), f_v is the radiation view factor, ε is the sample surface emissivity, σ is the Stefan–Boltzmann constant (Jm^{-2}K^{-4}s^{-1}), A_R is the sample radiation area (m^2), T_{sur} the average surroundings temperature (K), T_{shelf} is the shelf temperature (K), t_1 is the starting drying time (s), t_2 is the ending drying time (s), h_c is the contact heat transfer coefficient (J·m^{-2}·K^{-1}·s^{-1}) and A_c is the sample contact area (m^2).

$$Q_{total} = (h_c A_c \int_{t_1}^{t_2} (T_{shelf} - T_{ssmple})dt + \\ + f_v \varepsilon \sigma A_R (\int_{t_1}^{t_2} (T_{sur}^4 - T_{samle}^4)dt. \qquad (2)$$

The temperature of freeze drying process has significant influence both on of dried material quality, time of drying and costs of process [11,13,15,20]. Many studies concerning the increase of freeze drying capacity taking into account minimal energy consumption and good quality of product [1,2,16].

Vegetables are the most readily available sources of important proteins, vitamins, minerals and essential amino acids, in the diet. However due to the high moisture content, vegetables are very perishable with low storage life [4,5,6]. Freeze drying increases the shelf life to between 10 and 20 years of food without altering its reconstituted texture [21]. The aim of this work was to evaluate the influence of heating panel temperature on freeze drying energy requirements and selected quality parameters of dried celery, parsley and carrot.

MATERIALS AND METHODS

The material for investigation were roots of celery (cv. Makar), parsley (cv. Berlińska) and carrot (cv. Cezaro). Before drying, the raw materials were cut into 10 mm cubes. The process of drying was continued until the mass of the sample reached the constant moisture (5% w.b.). The convection dryer load was 3,5 kgm^{-2}. The investigation were carried out at the temperature of freeze dryer plates 40, 50, 60, and 70ºC and with the constant pressure in the drying chamber – 63 Pa.

The drying process was conducted using the freeze dryer ALPHA 1-4 (Fig. 1). This dryer consists of a drying chamber, cooling and heating systems, vacuum system, and a control and measuring system. Beside of this, the measuring stand consists of: electronic balance cooperated with Wing v.2.05 program and a electric power meter M4660-M cooperated with software Digiscop v.2.41 [19].

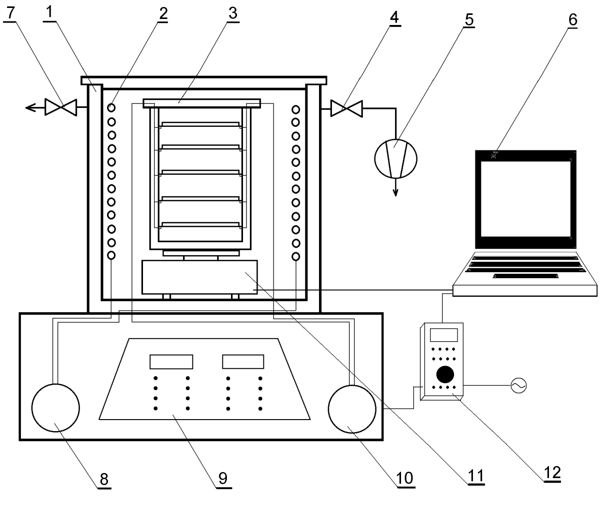

Fig. 1. Lyophilisator ALPHA 1-4: 1 – drying chamber, 2 – ice condenser, 3 – frame with heating plates, 4 – electro-magnetic valve, 5 – vacuum pump, 6 – computer, 7 – aeration valve, 8 – cooling system of ice condenser, 9 – control and measuring system, 10 – heating system, 11 – tensometric balance, 12 – electric meter

The rehydration of dried products was evaluated by ability of water absorption according to PN-90/A-75101/19. The content of L-ascorbic acid in raw material before and after drying was determined according to PN-A-04019:1998.

The measurement of the electrical energy supply to particular subassemblies of the lyophilisator, was registered as the power distribution during the drying process with a sampling constant of 0.5 s.

The total value of energy supplied for particular subassemblies of the lyophilisator during one cycle of drying was calculated by using the numerical integration method and spreadsheet [19].

The specific drying energy was calculated as the total energy supplied to lyophilisator during drying process related to 1 kg of dried raw material.

The investigations were replicated five times for each temperature of heating plates. The obtained data was further subjected to a statistical analysis and the consequent evaluations were analyzed for a variance analysis. Statistical tests were evaluated by using the Statistica 6.0 software (StatSoft, Inc., Tulsa, USA). All the statistical tests were carried out at the significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

The longest drying time of vegetables was noted at the temperature of heating plates $t = 40^{o}$C and the shortest at t = 70^{o}C The longest drying time was 610 min, 570 min and 510 min for celery, parsley and carrot, respectively, whereas the shortest time ranged from 210 min (carrot) to 260 min (celery). For all vegetables, as the temperature of heating plates increased a linear decrease of drying time was observed.

The analysis of variance confirmed that the temperature of heating plates has a significant influence on the drying time. (Tab. 1). An increase of temperature of heating plates caused a significant decrease of drying time for all vegetables (Fig. 2).

Table 1. The results of variance analysis of drying time under the influence of temperature of heating plates

Variable	Source of variance	Sum of squares within groups	p-value	F-test
Drying time	Temperature of heating plates	44.99331	7.99E-17	2.724944

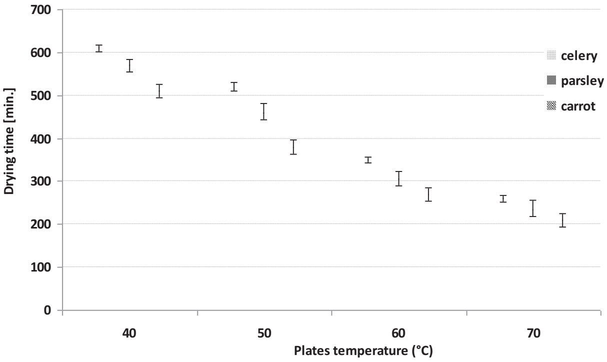

Fig. 2. The relation between the temperature of heating plates and drying time of vegetables

Table 2. The regression equations described the influence of heating plates temperature on specific drying energy

Raw material	Regression equation	R^2
Parsley	$e = -4.74\ t + 28.85$	0.9832
Celery	$e = -4.54\ t + 26.7$	0.9810
Carrot	$e = -4.12\ t + 24.1$	0.9778

Table 3. The results of variance analysis of specific drying energy under the influence of temperature of heating plates during freeze drying process

Variable	Source of variance	Sum of squares within groups	p-value	F-test
Specific drying energy	Temperature of heating plates	426.6838	1.9E-47	2.724944

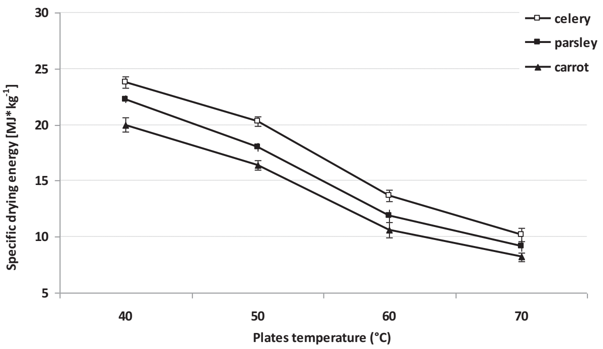

Fig. 3. Relation between temperature of heating plates and specific drying energy

The results showed a significant decrease of specific drying energy as the drying temperature increased (average from 22.0 to 9,2 MJkg^{-1}) (Fig. 3). It is caused by shortening of drying time. The highest specific drying energy was obtained during drying of celery and the lowest for carrot. The highest decrease of energy utilization was observed when drying temperature of heating plates increased from 50 to 60°C. The relations between drying temperature and specific drying energy were described by linear regression equations (Tab. 2).

The results of variance analysis confirmed that the temperature of heating plates has a significant influence ($\alpha = 0.05$) on specific drying energy during lophylization process (Tab. 3).

The results of dehydration rate for dried vegetables were presented on Fig. 4. An increase of heating plates temperature caused a slight but significant and linear decrease of dehydration rate of all vegetables (Tab. 4) The highest changes of rehydration index were obtained for dried celery (12% in the case of extreme temperatures of heating plates)

The roots of celery had the initial moisture content 86.3% and contained average 71.5 mg per 100 g of dry weight of L-ascorbic acid. Whereas the average value of this acid in carrot and parsley was 72.0 and 174.7 mg per 100 g of dry weight, respectively and the initial moisture content 85.4% and 83.8%, respectively.

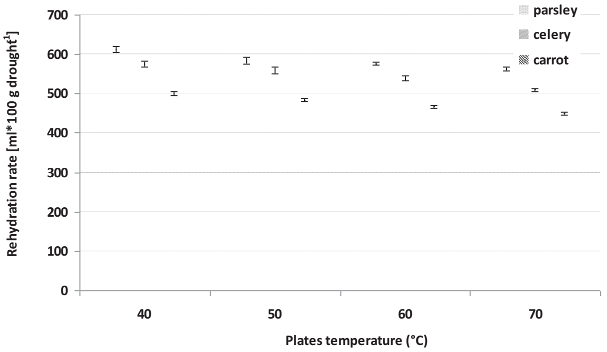

Fig. 4. Relation between temperature of heating plates and rehydration rate

Table 4. The results of variance analysis of rehydration rate under the influence of temperature of heating plates during freeze drying process

Variable	Source of variance	Sum of squares within groups	p-value	F-test
Rehydration index of dried material, R/Rmax	Temperature of heating plates	3420.678	5.85E-81	2.724944

The temperature of heating plates has a little influence on L-ascorbic acid content. However, the increase of temperature form 40°C to 70°C caused a significant decrease of this acid content, average about 13%, 17% and 18% for parsley, carrot and celery, respectively (Tab.). The highest changes of L-ascorbic acid content (decrease about 8-9%) were observed when drying temperature of heating plates increased from 60 to 70°C (Fig. 5). The changes of L-ascorbic acid in the function of heating plates temperature were described by using the quadratic equations.

Table 5. The results of variance analysis of L-ascorbic acid content under the influence of temperature of heating plates during freeze drying process

Variable	Source of variance	Sum of squares within groups	p-value	F-test
L-ascorbic acid content	Temperature of heating plates	791.9623	3.23E-57	2.724944

Table 6. The regression equations described the influence of heating plates temperature on L-ascorbic acid content

Raw material	Regression equation	R^2
Parsley	$L = -3.1\ t^2 + 8.7\ t + 149.6$	0.9934
Celery	$L = -1.65\ t^2 + 4.67\ t + 60.3$	0.9795
Carrot	$L = -1.25\ t^2 + 3.47\ t + 47.4$	0.9858

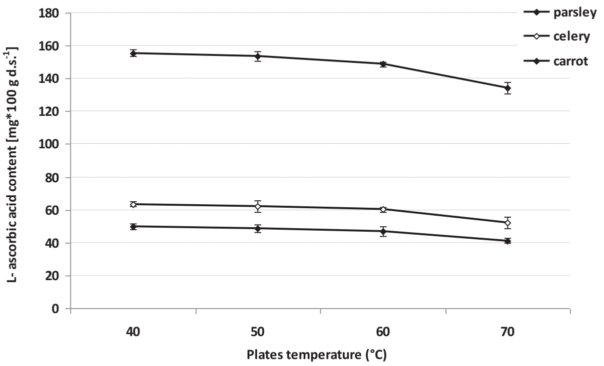

Fig. 5. Relation between temperature of heating plates and L-ascorbic acid content

CONCLUSIONS

1. The specific drying energy during lophylization process of vegetables decreased as temperature of heating plates increased (average from 22.0 to 9,2 MJkg^{-1}). The highest decrease of drying energy was observed when temperature increased from 50 to 60°C.
2. An increase of heating plates temperature caused a decrease of rehydartion index of dried vegetables. The highest changes of rehydration index (decrease about 12%) were obtained in the case dried celery
3. The content of L-ascorbic acid decreased as the temperature of heating plated increased. The highest changes of this acid were observed whet temperature increased from 60 to 70°C.
4. According to these results we can conclude that the optimum temperature of heating plates during freeze drying process of investigated vegetables is 60°C.

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ANALIZA WPŁYWU TEMPERATURY PŁYT GRZEJNYCH LIOFILIZATORA NA ENERGOCHŁONNOŚĆ PROCESU I CECHY JAKOSCIOWE SUSZU Z WYBRANYCH WARZYW

Streszczenie. W pracy przestawiono wyniki badań dotyczące wpływu temperatury płyt grzejnych na energochłonność procesu liofilizacji oraz wybrane cechy jakościowe warzyw (selera, pietruszki i marchwi). Na podstawie uzyskanych wyników stwierdzono, że wzrost temperatury płyt grzejnych powodował spadek jednostkowych nakładów energii suszenia (średnio o 60%). Następowało także pogorszenie wskaźnika rehydracji suszu oraz zmniejszenie zawartości kwasu L-askorbinowego. Największe zmiany tego kwasu odnotowano przy wzroście temperatury płyt grzejnych z 60 do 70°C. Za optymalną temperaturę liofilizacji badanych warzyw przyjęto 60°C.

Słowa kluczowe: liofilizacja, suszenie, energochłonność jednostkowa, jakość, warzywa.