

UNIVERSAL MODES OF TECHNOLOGICAL PROCESSING OF COLLOID CAPILLARY-POROUS MATERIALS BY CONVECTIVE DRYING METHOD

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Abstract. *Modern society is facing such problems of the 21st century as a pandemic, environmental crisis, greenhouse gas emissions and so on. Therefore, functional nutrition of people becomes extremely important, which is impossible without proper technological processing with maximum preservation of all BAS, and reduction of energy consumption in all industries. This in combination can strengthen social immunity and have a positive impact on the economy.*

Functional foods (according to the classification of the main plant functional ingredients of Dr. Petrova Zh.O.) include antioxidants based on table beets, carotene and phytoestrogens based on soy.

One of the most pressing issues is the high-quality processing of vegetable raw materials (colloidal capillary-porous materials) and improving the energy efficiency of drying processes. An important task in the processing of vegetable raw materials by dehydration is the preservation of biologically active substances.

We investigated the influence of drying parameters in order to maximize the preservation of BAS in dried antioxidant and phytoestrogenic raw materials. As a result of studies of drying kinetics, universal modes of dehydration have been developed: 60 °C and energy efficient step mode 100 / 60°C for antioxidant and phytoestrogenic plant raw materials, which maximally retain functional properties and allow to obtain high quality dried products and food powders. The use of such modes allows to intensify the drying process up to 40%.

Key words: *energy efficiency, drying kinetics, functional products, antioxidants, phytoestrogens*

Actuality. *The drying process is a complex set of interconnected processes of heat transfer to the material through the boundary layer, the stage of heat transfer; phase transformation, evaporation stage; transfer of moisture and heat inside the material, the stage of heat transfer; transfer of moisture and heat from the surface of the material to the environment through the boundary layer, the stage of heat and mass transfer, which is*

realized by diffusion or molecular transfer, characteristic of the transfer of mass of steam and inert gas; filtration or molar transfer under convection; of thermodiffusion, ie the transfer of moisture under the influence of a temperature gradient, while the direction of thermodiffusion of the mass flow density of the substance corresponds to the direction of heat flux density.

Modern nutrition science considers plant raw materials / CCPM as vital products because they are the main source of many biologically active substances. In Ukraine, beans and vegetables are seasonal and therefore subject to processing. In addition to dry matter, they contain from 25 % to 97 % water. During storage, they partially lose water and vitamins, which adversely affects their metabolism and leads to spoilage. Therefore, it is important to seasonally process vegetables and fruits, which will preserve the most biologically active substances with minimal energy costs for processing.

Processing of agricultural raw materials by existing drying methods for the production of functional dry food products belongs to the complex energy-intensive technological processes with increased requirements for the preservation of biologically active substances in the final product. In this regard, in Ukraine it is advisable to develop the direction of research and development of energy-efficient heat technologies for processing food products into dried products and functional powders.

Analysis of recent research and publications. The kinetics of the drying process of objects belonging to 2 groups of functional foods has been analyzed in this paper (according to the classification of the main plant functional ingredients Doctor of Engineering Petrova Zh.O.) – these are antioxidants and phytoestrogens.

Antioxidant plant raw materials include vegetables and fruits, which contain in their chemical composition such biologically active substances as carotenoids, dyes (betanine), lycopene, vitamin E, ascorbic acid, organic acids, etc. Among the vegetables, that grown in Ukraine, red beetroot occupies one of the first places due to the content of anthocyanin dyes - betanine. Betanine degrades under the action of light, temperature, oxygen.

To date, scientists have proposed various methods of drying red beetroot to stabilize the main red pigment. One way to improve the stability of natural dyes is the encapsulation process, which creates a barrier between the base material and the medium.

This barrier is formed by the auxiliary material (encapsulating agent), which protects the encapsulated material, making the final product more stable. The subject of the study is the encapsulation of the natural dye of red beetroot in combination with maltodextrin and xanthan gum, using freeze-drying and spray drying [1].

Polish scientists conducted a study of convective drying with pre-osmotic treatment. NaCl was taken as the osmotic agent [2]. Osmotic dehydration was performed in 5%, 15% and 25% NaCl solutions for 30, 60 and 90 minutes, respectively. Dried at temperature 65 °C. According to foreign scientists, this temperature is considered optimal for drying fruits and vegetables. The lowest value has a sample with a pre-osmotic treatment of 25% and a holding time of 90 minutes. The best value of 83.7% is a sample osmotically treated with 5% NaCl and kept for 30 minutes.

Known methods of processing red beetroot are characterized by either high energy consumption or cost of auxiliary materials, which increases the cost of the final product.

Soy contains a large amount of protein, fat and is considered the main supplier of phytoestrogens. During processing it is necessary to develop such modes which would not destroy all these components. Soybeans and other protein-containing legumes are considered to be an environmentally friendly source of protein that is stably available and able to support about 10 times more than the number of people in Japan who typically get protein mainly from beef and pork [3].

Scientists from Korea (College of Agricultural and Natural Sciences and National Institute of Plant Sciences) are studying the processes of drying soybeans using interval drying [4]. One of the studies was that 25 g of raw soybeans were convectively dried at temperatures of 35 °C, 40 °C and 45 °C, the speed of the coolant (dry air) was 3 m/s. The total drying time was 600 minutes. Every 30 minutes, a change in the mass of the material was recorded. The initial humidity was 22%, drying lasted until the residual moisture content - 7.7%. As a result, such studies have shown that periodic drying gave a higher rate of decrease in moisture content mainly due to the diffusion of moisture from the center to the surface during the rest period. Thus, interval drying can help reduce the energy consumption required for drying soybeans [4].

Also, according to the classification of Doctor of engineering Petrova Zh.O., along with soy a large amount of phytoestrogens contains rapeseed, which makes it no less interesting object of study of the processes of drying of colloidal capillary-porous materials.

Purpose of research. From the analysis of recent research and publications, the question arises about the need to study the impact of technological parameters of the processes of preparation and dehydration of vegetable raw materials on energy consumption in the manufacture of dry food products. In particular: the process of preliminary creation of phytoestrogenic (mixtures (1:1): soy-carrot; soy-beet; soy-sweet; soy-spinach), antioxidant (mixture of red beetroot-tomato (3:1)), carotene-containing (mixture of rape-carrot) (1:2)) plant compositions and the use of stepwise mode of increasing the coolant temperature during drying.

Materials and methods of research. For this purpose, experimental studies of the drying process of prepared raw materials at different temperatures on a convective drying stand in a wide range of mode parameters were conducted, with continuous automatic collection and processing of information about changes in mass, sample temperature using the developed application "Sooshka", which allows calculations with construction of drying curves [5]. The prepared mono-raw material and compositions were poured on a mesh tray measuring 100x50 mm, which was placed on a barbell in the drying chamber. Thermocouples were inserted inside the material to measure the temperature change of the material during drying. Studies of the drying process were performed to the final moisture content of the material $W_k^c = 4 \%$, because, as is known, the drying of materials to a moisture content below 5% can significantly increase their shelf life in powder form. To determine the current moisture content of the material, the samples were dried after the experiment to a completely dry weight at 100...105 °C (GOST 28561–90 «Determination of humidity by the method of drying to constant weight»).

Research results and their discussion. The main characteristic of antioxidant raw materials based on red beetroot is the preservation of betanine in the processing of raw materials. Preservation of betanine depends on the pH of the medium, the temperature of the coolant. Since the pH of red beetroot is 6.0, at the stage of preparation of raw materials

for drying by blending (combination of red beetroot with vegetable raw materials with high acid content, in this case - tomato in different ratios) was created beet-tomato composition 3: 1, which makes it possible to obtain the optimal pH value in the range of 3.9 to 4.0 [6].

Dehydration of vegetable raw materials, as mentioned above, is one of the most important technological processes on which the quality of finished products depends. The study of the kinetics of the drying process of beet-tomato composition from the temperature is presented in Fig. 1, *a*. The curves have a characteristic appearance for colloidal capillary-porous materials. As the coolant temperature increases, the intensity of the drying process of the composition increases. At a coolant temperature of 60 °C, the duration of the process is 100 minutes, which is 1.8 times more than the temperature of 100 °C.

The effect of coolant temperature on the drying rate of the composition is presented in Fig. 1, *b*. As the temperature rises, the material heats up more intensively and accelerates the release of free moisture, as a result of which the first critical drying point is moved. It shifts to the left and occurs later than in mild drying modes.

The initial humidity of the components is different, it is the highest in the tomato, respectively, the drying time of which is 130 minutes, the drying time of table beets is 85 minutes, and the composition is 100 minutes.

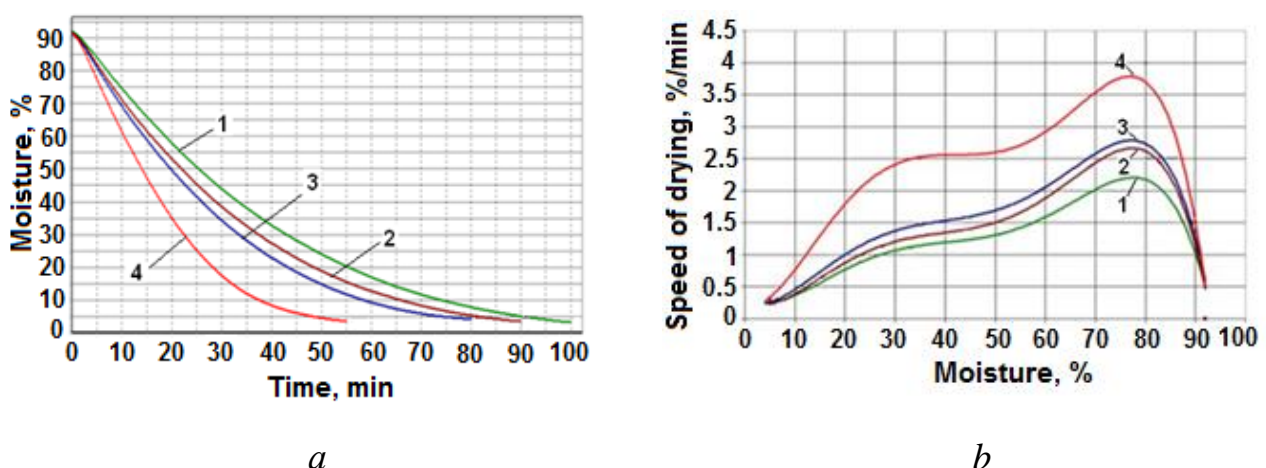


Fig. 1. Influence of coolant temperature on process kinetics drying (*a*) and on speed of drying (*b*) red beetroot composition (3:1) $\delta = 10$ mm, at $V = 3,5$ m/s; $W_{кв} = 8$ %; $d = 10$ g/kg dry air:

1 – 60 °C; 2 – 70 °C; 3 – 80 °C; 4 – 100 °C

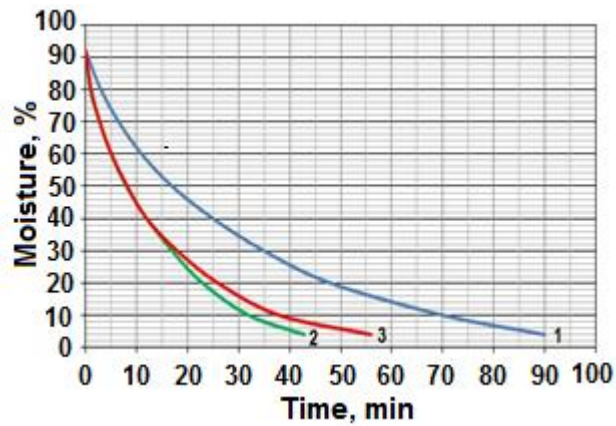
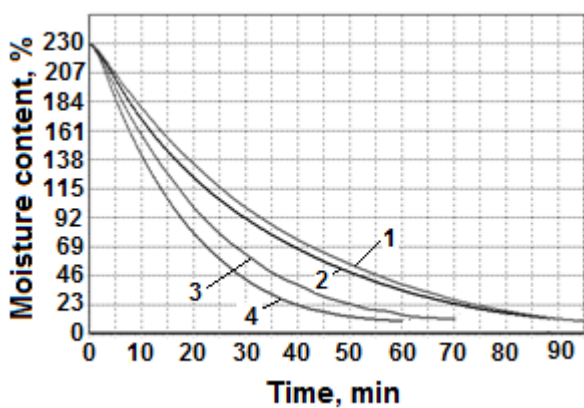


Fig. 2. The influence of the stepwise drying mode on the kinetics of the drying process of the beet-tomato composition (3:1):

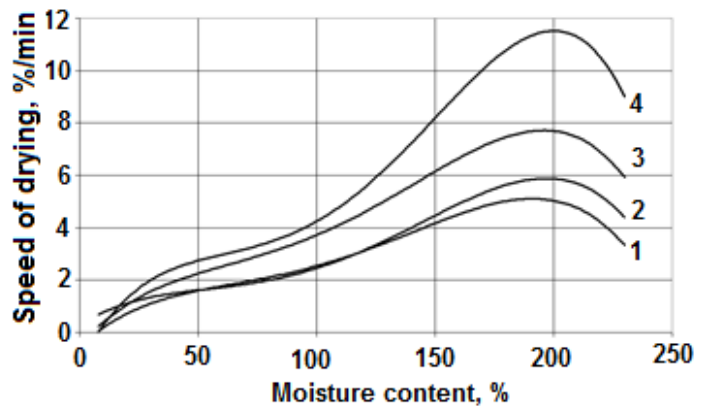
1 – 60 °C; 2 – 100 °C; 3 – 100/60 °C; $V = 3,5$ m/s, $\delta = 10$ mm, $d = 10$ g/kg dr.a

A stepwise drying mode was developed (Fig. 2), which shows that the drying process is intensified by 37.8% compared to the drying mode of 60 °C, and betanine remains at the level of 95-97 %.

The composition of rapeseed-carrot without hydrothermal treatment and the composition of soybean-carrot were selected ; soybeans; soy-sweet; soybeans-spinach treated hydrothermally was selected for the study of phytoestrogenic raw materials. To prevent oxidation of soy and rapeseed lipids, they were combined with vegetables. Mixtures have not only phytoestrogenic properties, but thanks to pectin substances which contain vegetables, also possess complexing properties [7].



a



b

Fig. 3. Influence of heat-coolant temperature on drying kinetics (a) and heat-coolant temperature on drying rate (b) of rape-carrot composition (1: 2) $\delta = 10$ mm at $V = 3,5$ m/sec; $W_k^c = 8$ %; $d = 10$ g/kg dry air:

1 – 60 °C, 2 – 70 °C, 3 – 80 °C, 4 – 100 °C

Studies of the effect of temperature, speed of coolant and layer of rapeseed-carrot mixture on the kinetics of the drying process are shown in Fig. 3 a, b and 4 [7].

As the coolant temperature increases, the drying time decreases, in the temperature range from 60 to 70 °C it decreases by 8%, and further temperature increase from 70 to 80 °C reduces the duration by 25 %, and from 80 to 100 °C - by 16 % (Fig. 3.a) [7].

Increasing the heat-coolant temperature above 80°C leads to lipid oxidation and partial destruction of carotenoids, as discussed earlier. Therefore, the effect of velocity and layer of material on the quality of dried raw materials is investigated at the temperature of the heat-coolant 70 °C (fig. 3,b) [7].

Drying of rapeseed-carrot mixture occurs during the period of falling drying speed with preheating of the material. In the drying mode $t = 70\text{ °C}$; $V = 3,5\text{ m/sec}$; $\delta = 10\text{ mm}$ the maximum drying speed is 11,5 %/min. The final temperature of the mixture 78 °C [7].

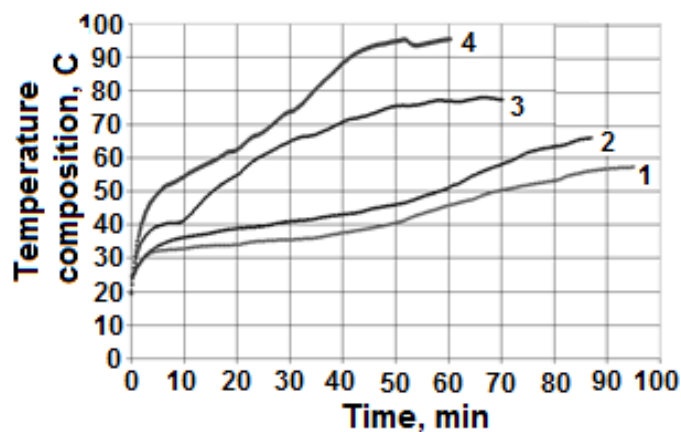


Fig. 4. The effect of heat-coolant temperature on the temperature change in the middle of the layer of rapeseed-carrot composition $\delta = 10\text{ mm}$ at $V = 3,5\text{ m/sec}$; $W_k^c = 8\%$; $d = 10\text{ g/kg dry air}$:

1 – 60 °C, 2 – 70 °C, 3 – 80 °C, 4 – 100 °C

A study of antioxidant and phytoestrogenic raw materials showed that the greatest influence on the drying kinetics and quality of the material comes from the temperature of the heat-coolant [7].

The temperature change in the middle of the layer is 10 mm, as can be seen from Fig. 4, occurs more slowly at drying modes of 60, 70 °C and more noticeable growth is observed at temperature increase to 80 – 100 °C [7].

A very important step before drying is the preparation of raw materials for drying, which includes pre-hydrothermal treatment of phytoestrogenic raw materials, during which anti-food components are inactivated. The high drying time of pre-hydrothermally treated crushed soybeans determines the relevance of the intensification of the process and the development of energy-efficient drying regimes with maximum preservation of biologically active substances of raw materials and high final quality of the dried material.

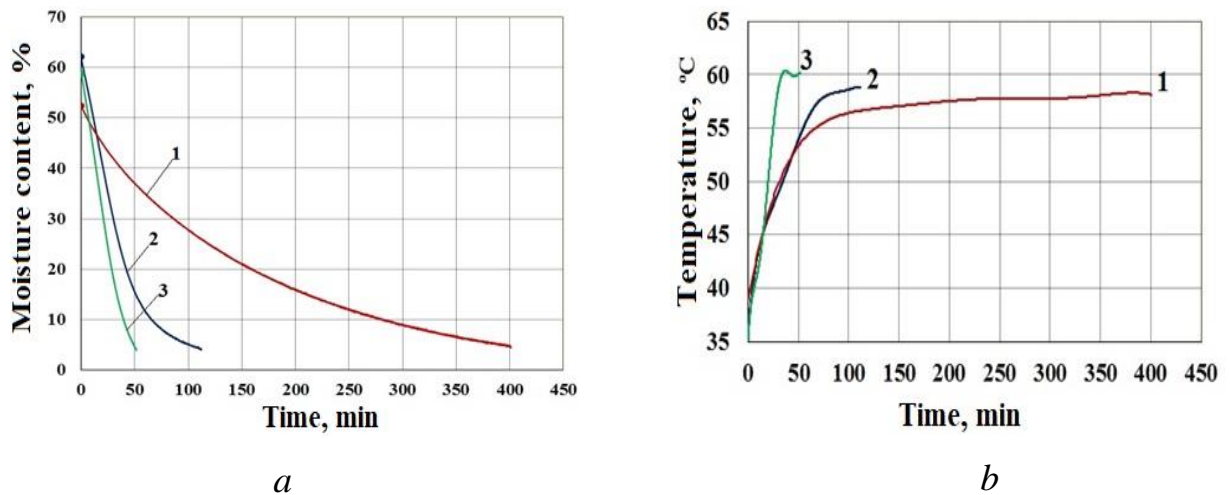


Fig.5. Change in moisture content (a) and temperature in the middle of layer (b) of mono-raw material and soy-sweet mixture at regime parameters: $t = 60^{\circ}\text{C}$, $v = 2,5 \text{ m/sec}$; $d = 10 \text{ g/kg dry air}$, $\delta = 15 \text{ mm}$:

1 – sweet potatoes ($W_{st} = 52 \%$), 2 – soy ($W_{st} = 62 \%$), 3 – soy-sweet mixture ($W_{st} = 58 \%$)

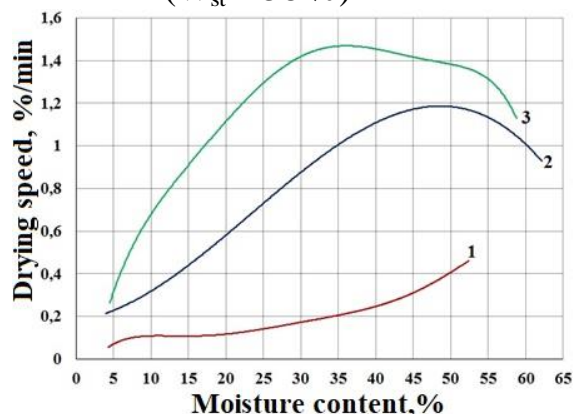


Fig.6. Change in the drying rate of mono-raw material and soy-sweet mixture (1: 1) from the moisture content of the material. Mode parameters: $t = 60^{\circ}\text{C}$, $V = 2,5 \text{ m/sec}$, $\delta = 15 \text{ mm}$, $W_{\kappa}^c = 4 \%$; $d = 10 \text{ g/kg dry air}$:

1 – sweet potatoes, 2 – soy, 3 – soy-sweet mixture

The effect of the components of the composition on the kinetics of the drying process was studied in soybean-vegetable compositions, where the vegetable component was sweet potatoes.

Studies of the influence of components on the kinetics of the drying process were also conducted on samples of soy-sweet mixture, using a vegetable component - Vietnamese sweet potatoes, which were grown on soils in the Socialist Republic of Vietnam [8].

Forms of drying curves, fig. 5, characteristic of colloidal capillary-porous materials. The use of high-temperature drying mode above 65-70 °C leads to the destruction of carotene containing sweet potatoes, so it is advisable to use the drying mode at a heat-coolant temperature of 60 °C (Fig. 5).

In the course of research conducted to intensify the drying process of pre-hydrothermally processed crushed soybeans and stabilization of their fats, it was found that not only this is achieved by combining soy with sweet potatoes. Vietnamese sweet potato, by its structural properties, is an object with a long drying time. In order to dry it to the required final humidity of 4-6 % it is necessary to spend 6 hours. 40min. From fig. 5 shows that when soybeans are combined with Vietnamese sweet potatoes in a mixture with a component ratio of 1:1, there is a significant reduction in drying time by 8 times and is 50 minutes relative to sweet potatoes.

Curves of changes in the drying rate from the moisture content of the material (fig. 6) confirm the feasibility of developing a soy-sweet mixture (curve 3), characterized by higher drying rates (maximum drying rate $N_{\max} = 1.45$ %/min) for soybean mono-components (curve 2) and sweet potatoes (curve 1).

In order to intensify and energy efficiency of the process, stepwise drying regimes were developed for soybean-carrot and soybean-spinach mixtures (the ratio of components in the mixtures was as 1:1) 100/70°C and 100/60°C, respectively.

It is worth noting that the step mode 100/60°C was used for soy-spinach mixture, because spinach is a more thermolabile material, the addition of which allowed to preserve the nutrients of the original components, color and taste of the original components. [5].

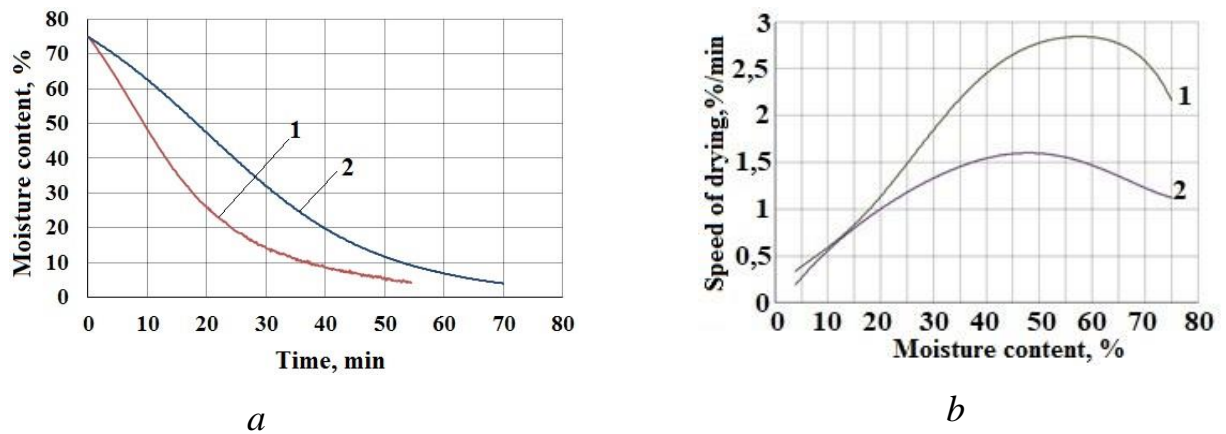


Fig. 7. Change in moisture content (a) and drying rate (b) of soybean-spinach mixture under the influence of heat-coolant temperature 60°C and 100/60°C. Mode parameters: $\delta = 15$ mm, $W_{\kappa}^c = 4$ %; $v = 2,5$ m/sec, $d = 10$ g/kg dry air: 1 – 100/60 °C, 2 – 60 °C

Figure 7 (a) shows the change in moisture content of soybean-spinach mixture under the influence of heat-coolant temperature 60 °C (curve 2) and 100/60 °C (curve 1). As a result of development of the step mode of dehydration of phytoestrogenic mix on the basis of soy and spinach there is an intensification of process by 21 % [5].

From the comparison of curve 1 and 2 of fig. 7 (b): the use of step mode 100 / 60 °C allowed to increase the average process speed, the maximum drying rate $N_{\max} = 2.8$ % / min (curve 1 fig.7 (b)), which is 1.75 times higher than the mono mode 60 °C (curve 2, fig. 7 (b)) [5].

When studying the effect of the gradual change in coolant temperature on the drying process of soybean-beet mixture (ratio of components 1:1, $W_n = 75$ %), the heat-coolant temperature was reduced from the initial 100 to 60 °C when the temperature in the material layer approached the allowable (60 °C). From the comparative analysis of temperature modes, it is established: step (100/60 °C) change of temperature of the heat carrier at drying of soy-beet mix allows to reduce drying time in comparison with a monotemperature mode [7].

During the study of the quality of phytoestrogenic raw materials, we chose a combination of soybeans-carrots treated hydrothermally, rapeseed-carrots without hydro-thermal treatment. Also studied compositions based on soybeans with pre-hydro-thermal treatment, such as soybeans, soybeans, onions, soybeans, peas, soybeans-spinach, soybeans-sweet potatoes, soybeans-carrots, chopped soybeans This raw material contains a large amount of fats 20-40 %, which in the process of processing are oxidized and in turn

destroy biologically active substances. By creating a composition, pre-hydrothermally treated and crushed soybeans, the acid number is stabilized during drying. Therefore, the effect of coolant temperature during drying was investigated by determining the change in acid number. Thus, it was found that temperatures of 60 °C and 100/60 °C do not lead to oxidation of fats of the studied raw materials, and during storage, the combined soy-based powder is stored for 9-10 months [5].

Conclusions and prospects. The generalized analysis of the obtained data confirmed that the temperature regime of 60 °C is effective and safe for biologically active substances contained in antioxidant, phytoestrogenic and carotene-containing mixtures. The use of stepwise drying mode 100 / 60 °C intensifies the drying process of antioxidant (37.8 %) and phytoestrogenic mixtures (21 %), and also does not lead to deterioration of the quality characteristics of the final product.

Thus, the universality of this step mode makes it possible to reduce energy costs for convective drying and can be used in mass production of functional powders, which are an available source of natural vitamins and minerals to strengthen human immunity during epidemics and exacerbations of viral diseases. This is confirmed by the positive conclusion of the Institute of Gerontology DF Chebotaryova National Academy of Medical Sciences of Ukraine.

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УНІВЕРСАЛЬНІ РЕЖИМИ ТЕХНОЛОГІЧНОЇ ПЕРЕРОБКИ КОЛОЇДНИХ КАПІЛЯРНО-ПОРИСТИХ МАТЕРІАЛІВ МЕТОДОМ КОНВЕКТИВНОГО СУШІННЯ

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Анотація. *Сучасне суспільство зіткнулось із такими проблемами 21 століття як пандемія, екологічна криза, викиди парникових газів тощо. Тому стає надзвичайно важливим функціональне харчування людей, яке неможливе без правильної технологічної переробки з максимальним збереженням всіх БАР, та зменшення споживання енергії у всіх галузях промисловості. Це в комплексі може підсилити суспільний імунітет та позитивно вплинути на економіку.*

До функціональних продуктів харчування (за класифікацією основних рослинних функціональних інгредієнтів д.т.н. Ж. О. Петрової) відносяться антиоксидантні на основі столового буряку, каротиновмісні та фітоестрогенні на основі сої.

Одним із найактуальніших питань є високоякісна переробка рослинної сировини (колоїдні капілярно-пористі матеріали) та покращення показників енергоефективності процесів сушіння. Важливим завданням при переробці рослинної сировини методом зневоднення є збереження біологічно активних речовин.

Нами було досліджено вплив режимних параметрів сушіння з метою максимального збереження БАР у висушеній антиоксидантній та фітоестрогенній сировині. У результаті проведених досліджень кінетики сушіння, розроблено універсальні режими зневоднення: 60 °С та енергоефективний ступеневий режим 100/60 °С для антиоксидантної та фітоестрогенної рослинної сировини, які максимально зберігають функціональні властивості та дозволяють отримати високоякісну сушену продукцію та харчові порошки. Застосування таких режимів дозволяє інтенсифікувати процес сушіння до 40 %.

Ключові слова: *енергоефективність, кінетика сушіння, функціональні продукти, антиоксиданти, фітоестрогени*

УНИВЕРСАЛЬНЫЕ РЕЖИМЫ ТЕХНОЛОГИЧЕСКОЙ ПЕРЕРАБОТКИ КОЛЛОИДНЫХ КАПИЛЛЯРНО-ПОРИСТЫХ МАТЕРИАЛОВ МЕТОДОМ КОНВЕКТИВНОЙ СУШКИ

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Аннотация. Современное общество столкнулось с такими проблемами 21 века, как пандемия, экологический кризис, выбросы парниковых газов и т.д. Поэтому становится чрезвычайно важным функциональное питание людей, которое невозможно без правильной технологической переработки с максимальным сохранением всех БАВ, и уменьшения потребления энергии во всех отраслях промышленности. Это в комплексе может усилить общественный иммунитет и положительно повлиять на экономику.

К функциональным продуктам питания (по классификации основных растительных функциональных ингредиентов д.т.н. Ж. О. Петровой) относятся антиоксидантные на основе столовой свеклы, каротиносодержащие и фитоэстрогенные на основе сои.

Одним из самых актуальных вопросов является высококачественная переработка растительного сырья (коллоидные капиллярно-пористые материалы) и улучшение показателей энергоэффективности процессов сушки. Важной задачей при переработке растительного сырья методом обезвоживания является сохранение биологически активных веществ.

Нами было исследовано влияние режимных параметров сушки с целью максимального сохранения БАВ в высушенном антиоксидантном и фитоэстрогенном сырье. В результате проведенных исследований кинетики сушки, разработаны универсальные режимы обезвоживания: 60 °С и энергоэффективный ступенчатый режим 100/60 °С для антиоксидантного и фитоэстрогенного растительного сырья, которые позволяют максимально сохранить функциональные свойства и получить высококачественную сушеную продукцию и пищевые порошки. Применение таких режимов позволяет интенсифицировать процесс сушки до 40 %.

Ключевые слова: энергоэффективность, кинетика сушки, функциональные продукты, антиоксиданты, фитоэстрогены