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ADSORPTION PROPERTIES OF FAST-FOOD PRODUCTS

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Abstract
Fast food has become an integral part of human life today. However, most of these products have a negative impact on the body due to a large number of chemical additives. That is why we have developed an innovative preparation of raw materials for drying and convective drying technology, which allows us to preserve more than 90% of vitamins and other biologically active substances in vegetables, fruits and berries without the presence of additional ones. The ingredients used to make fast food products such as soups, cereals and desserts. Our products contain vitamins, micro and macro elements, enzymes that increase their biological value and have functional properties (antioxidant, folate-containing, prebiotic and phytoestrogenic), normalise metabolism and enhance the body's defence functions. The aim of this work is to study the adsorption capabilities of fast-food products, which allow us to determine storage conditions and equilibrium humidity. Previously, we have studied the adsorption capabilities of plant powders as a component of fast food products, which showed their equilibrium moisture content and shelf life. We studied 2 puree soups and 2 porridge with milk. The studies were carried out using the Van Bamelen static method. The obtained kinetic curves and sorption isotherms show that instant foods are capillary-porous colloidal bodies and, having the same forms of moisture binding (adsorption, capillary and osmotic), at the same time, they differ significantly in equilibrium moisture content. It was found that the equilibrium moisture content of convenience foods is in the range of 7.5-9.2 %. This made it possible to avoid overdrying the ingredients and to create efficient storage conditions.
Keywords: adsorption; equilibrium moisture content; convenience foods.

АДСОРБЦІЙНІ ВЛАСТИВОСТІ ПРОДУКТІВ ШВИДКОГО ПРИГОТУВАННЯ

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Анотація
Продукти швидкого харчування сьогодні стали не від'ємною складовою життя людини. Але більшість таких продуктів негативно вливають на організм завдяки великій кількості хімічних домішок. Тому нами була розроблена інноваційна підготовка сировини до сушіння та технологія конвективного сушіння, яка дозволила зберегти понад 90% вітамінів та інших біологічно активних речовин в овочах, фруктах та ягодах, без присутності додаткових. На основі яких зроблені продукти швидкого харчування інгредієнтів, такі як супи, каші та десерти. Наші продукти містять вітаміни, мікро і макроелементи, ферменти, що підвищують їхню біологічну цінність та мають функціональні властивості (антиоксидантні, фолатомісткі, пребіотичні та фітоестрогенні), нормалізують обмін речовин та підсилюють захисні функції організму. Метою даної роботи є дослідження адсорбційних можливостей продуктів швидкого приготування, які дозволяють визначити умови зберігання та рівноважну вологість. Раніше нами були виконані дослідження адсорбційних можливостей рослинних порошків як складової продуктів швидкого приготування, які показали їх рівноважні вологості та терміни зберігання. Було досліджено 2 супи-пюре та 2 каші з молоком. Дослідження виконані за тензометричним (статичним) методом Ван Бамелена. Отримані кінетичні криві та ізотерми сорбції, показують, що продукти швидкого приготування представляють собою капілярно-пористі колоїдні тіла і маючи однакові форми зв'язування вологи (адсорбційну, капілярну та осмотичну) в той же час суттєво відрізняються один від одного рівноважною вологістю. Встановлено, що рівноважні вологості продуктів швидкого приготування знаходяться в межах 7.5–9.2 %. Це дозволило не пересушувати інгредієнти та визичити ефективні умови зберігання.
Ключові слова: адсорбція; рівноважна вологість; продукти швидкого приготування.

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Introduction

The armed full-scale invasion of the Russian army has led to a change in the attitude towards the interests of the army and the satisfaction of its needs. Modern warfare is not only a competition between offensive and defensive means, but also a competition between innovative technologies aimed at reducing the use of energy resources, the speed and cost of production, improving the quality of products to create comfortable living conditions in temporary structures, and providing adequate nutrition and treatment for the military personnel of the Armed Forces of Ukraine. Special attention should also be paid to nutrition of the population in special conditions (floods, earthquakes, evacuation after destruction, etc.). Such nutrition requires new high-quality products. The development of energy-efficient heat technology for the production of innovative fast-food products for hot meals is an important task, as people's health depends on it.

Today, the world is rapidly developing the area of research and production of functional foods, which are created purposefully as products with certain properties aimed at maintaining and improving human health.

Functional food plays an important role in maintaining a healthy lifestyle and reducing risk factors for various diseases. Most foods have a functional element that is responsible for improving health. All foods, such as fruits, vegetables, cereals, meat, fish, and dairy products, contain functional ingredients. A wide range of natural substances of plant and animal origin containing active components that play a role in physiological actions deserve attention for their optimal use to maintain health [1–5].

Functional foods have gained wide popularity around the world, and they are commonly known as "nutraceuticals" [1].

Functional foods, whether natural or processed, are defined as those containing one or more bioactive food ingredients: chemicals or other food components that have a positive effect on human health, including vitamins [6], carotenoids [7], flavonoids [8], and prebiotics [9], among others [10]. They have been shown to reduce the risk of cancer [11–13], diabetes [13; 14], autoimmune disorders [15; 16], obesity [13; 17; 18], cardiovascular disease [18; 19], and many others [20; 21].

Most functional foods on the market today contain dried products. Drying preserves the original products that have a short shelf life, reduces the weight of the product, concentrates biological substances by 6–8 times, makes transportation and easy consumption possible, and extends their shelf life.

Processing agricultural raw materials into functional foods is a complex, energy-intensive process with high requirements for the final product. In other words, in each case, it is necessary to solve the problem of preserving the naturalness of raw materials and simultaneously meeting the criteria of safety, shelf life, and manufacturability in further use. Drying technologies are particularly energy-intensive [22].

In the classical sense, drying is the process of removing moisture from a material, which changes the structural, mechanical, technological, and biological properties caused by a change in the form of moisture bonding [23]. It is known that after dehydration, capillary-porous bodies become brittle, have little compression and can be easily processed into a powdered state; colloidal bodies change their size significantly with changes in moisture content, but retain plastic or elastic properties; colloidal capillary-porous bodies have a capillary-porous structure, and the walls of capillaries have properties limited by the swelling of colloidal bodies (berries, fruits, vegetables, skin, fabrics, wood) [23].

The most common methods of drying colloidal capillary-porous materials today are sublimation, convection, infrared radiation, spraying, and solar. Of these methods, convective drying produces high-quality material with lower energy consumption.

The Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine has developed a tunnel-type steam convective drying plant that can consist of one, two, three or five drying zones, the number of which is determined by its capacity and cooling zone. Each drying zone has two half-zones. Two trolleys are placed in each half-zone of steam dryers. One trolley is placed in the cooling zone (Fig. 1) [24]. The dryer consists of prefabricated metal sections that form a tunnel with zones. The outer walls of the dryer body can be made of brick. The body (tunnel) consists of three drying zones and a cooling zone. Each zone has a ventilation unit installed outside the workshop to circulate the coolant.

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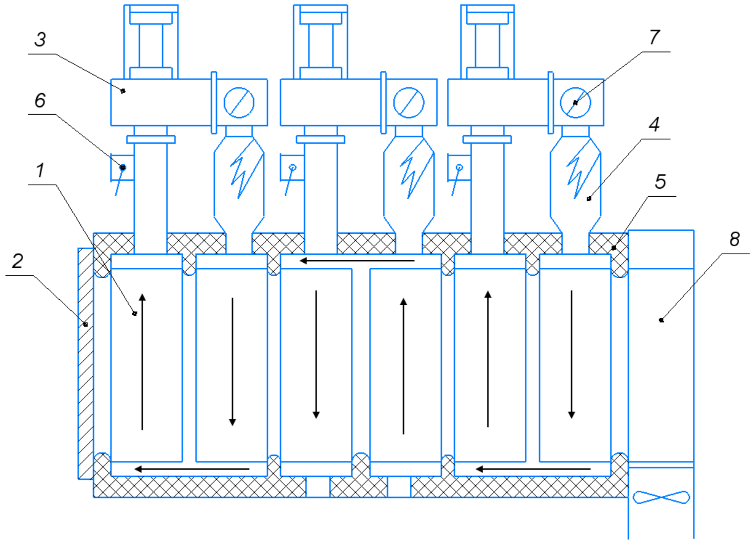

Fig. 1. Three-zone steam dryer TF.4.10: 1 –drying zone; 2 – dryer gate; 3 – dryer fan; 4 – heat generator; 5 – seal; 6 – biofilter valve; 7 – exhaust valve; 8 – cooling zone

The advantages of steam dryers are their versatility, automated control, environmental friendliness, and lower energy consumption compared to fossil fuel heat generators. The disadvantage is the intense deposition of salts (scale) on the surface of the heating elements, which can lead to their burnout and an increase in the processing time of plant material used for food purposes.

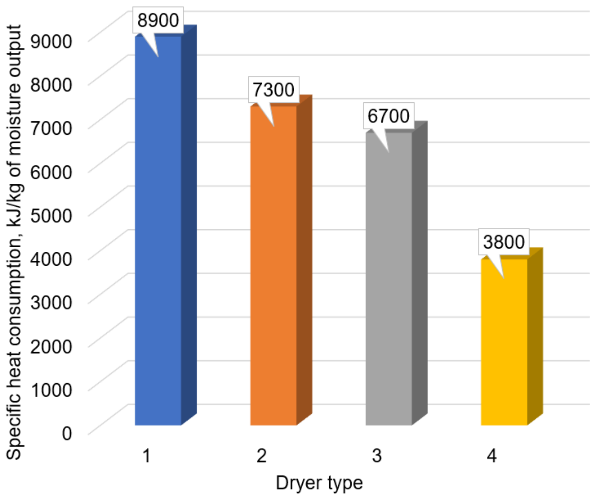

Fig. 2. Specific heat consumption in tunnel dryers during drying of vegetables and fruits: 1 – MNIPI-1; 2 – B6-KF, Russia; 3 – Cacak, Serbia; 4 – SUM-2, IET, Ukraine

Comparison of tunnel dryers in terms of specific heat consumption showed that the most economical dryers are those manufactured by IET (Ukraine), with energy consumption of 3800 kJ/kg of evaporated moisture (Fig. 2).

In our further research, we used a dryer developed at the Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine to produce powders.

The obtained dried functional combined plant powders are divided into 4 groups, according to the classification of the main plant functional ingredients, which were highlighted in the work of Petrova Zh.O. – antioxidant, phytoestrogenic, folate-containing and prebiotic. On the basis of functional powders, dry instant foods have been developed, such as soups (borscht, pea soup, buckwheat soup, etc.), sweet and savory porridges (oatmeal-carrot porridge with milk, pumpkin porridge with milk, buckwheat porridge with meat, etc.), desserts.

The qualitative and quantitative composition of functional convenience foods provides the human body with substances from which its cells and tissues can synthesize their own structures, which are necessary for vital processes, adaptive and protective functions.

The functional powders were used to develop instant foods in which all the ingredients are balanced to meet the body's optimal nutritional and energy needs.

Based on functional pumpkin powder, we have developed instant pumpkin porridge that does not require boiling; it is steamed with water at a temperature of 90–100 °C for 3–5 minutes. Due to its chemical composition, this product enhances the physiological functions of the body, it is recommended for therapeutic and preventive and baby food. Due to the high content of pumpkin carotenoids, pumpkin porridge is an antioxidant food. Pumpkin porridge in the diet will provide a healthy immune system and natural detox.

When considering the technological properties of the tested samples of combined powders and products based on them, obtained from vegetables and fruits, equilibrium moisture content is of great importance, which determines not only their storage conditions but also their final moisture content during drying.

The main objective of this work was to determine the equilibrium moisture content of the samples under study and to compare the adsorption properties of functional combined powders and a hot food product based on them. It is possible to obtain a realistic assessment of the shelf life and storage conditions of the developed new food products only as a result of studies of adsorption properties.

Experimental part

Materials and Methods

Adsorption studies were performed on functional instant foods and their components, namely pea and buckwheat puree soups, oatmeal-carrot porridge with milk, and pumpkin porridge with milk.

To determine the equilibrium moisture content of the samples under study depending on the relative humidity of the air, the Van Bamelen strain gauge (static) method was used. The essence of the method is that samples of material with a predetermined moisture content are kept in desiccators over aqueous solutions of sulfuric acid. A known concentration of solutions corresponds to a certain partial vapor pressure at a given temperature, i.e., the corresponding value of the relative pressure [25].

The samples adsorb water from the surrounding air on the outer and inner highly developed surface, since their surface has free energy. Adsorption on the surface of a solid dispersed body occurs spontaneously and until a dynamic equilibrium state of this thermodynamic system is established. Due to the variety of forms of moisture bonding with dispersed materials, the analytical structure of sorption isotherms of dispersed materials is complicated. So far, the sorption isotherm equation has been derived analytically only for the Langmuir isotherms of capillary-porous bodies. Therefore, we, like most researchers, chose the empirical way to determine the equilibrium moisture content [25].

The transfer potential in the adsorption process is the partial vapor pressure. The equilibrium in the system occurs when the partial pressure of air $p_{v\ air}$ and vapor in a thin layer above the material $p_{v\ mat}$ are equalized, i.e., when $p_{v\ air} = p_{v\ mat}$, at the same temperature of air and material. Under these conditions, the material assumes a constant moisture content We, which is called equilibrium, and equilibrium in the system is understood only as dynamic. If the material gains moisture ($p_{v\ air} > p_{v\ mat}$), it is sorbed, and if it loses moisture ($p_{v\ air} < p_{v\ mat}$), it is desorbed [21].

In the equilibrium state, the moisture content of the material W_p is the same at any point.

The water vapor content in the air is usually determined by the relative humidity φ, equal to the ratio of the partial pressure of air vapor p_v air to the saturation pressure p_s at the same temperature above water.

Since the reference literature gives the dependence of water vapor pressure over sulfuric acid solutions in mm Hg on the concentration of H_2SO_4 in weight %, we converted this pressure to relative humidity φ using Formula 1:

$$\varphi = \frac{p}{p_S} \qquad (1)$$

where p and p_s are the partial pressure and saturation pressure of water vapor at a pressure of 760 mm Hg and temperatures covering the possible range of their change in the experiment. The results of the recalculation are presented in [25].

In the reference books in tabular form are given the dependence of water vapor pressure over solutions on the weight % of H_2SO_4 in the solution (i.e., its concentration), as well as the dependence of the content of H_2SO_4 in grams per 100 g solution and per 1 liter of solution on the density of the solution in g/cm^3 at 20 °C for an acid with a density of 1.8305 [25].

Since the determination of the equilibrium moisture content of functional dry foods had to be carried out in the range of relative humidity φ from 0.4 to 0.9, which is typical for production conditions, the necessary characteristics of sulfuric acid were determined from the conversion table and reference data [25]. The experiments were conducted at an ambient air temperature ranging from 20 ± 0.5 °C.

It is advisable to calculate the equilibrium moisture content in relation to the absolutely dry mass of the material, since this value remains unchanged in the processes of sorption-desorption and drying-moistening, so when processing all experimental data, the moisture absorbed by the material was referred to the mass of the absolutely dry material [25].

Thus, the sorption isotherms $W^s{}_e = f(\varphi)$ in the studied range of relative humidity and the sorption kinetics curves $W^s = f(\tau)$ were obtained, since the experimental design also provided for the possibility of recording changes in sample humidity over time [25].

Results and discussion

The kinetic curves of water vapor adsorption by samples of combined powders with a particle size of d < 0.5 mm at the ratio of components specified for each powder obtained as a result of the experiments are presented in the previous work [25].

To determine the equilibrium moisture content of instant dry foods, exciters with relative humidity values of φ = 0.4, 0.6, 0.8, 0.9 were used.

Figure 3 shows the kinetic curves of water vapor adsorption of mashed pea soup. As can be seen from Figure 3, at φ = 0.4; 0.6, the equilibrium humidity is established on day 7 and 9, respectively. At φ = 0.8 – on day 19, and at φ = 0.9 – and on day 32, the equilibrium humidity increases.

Figure 4 demonstrates the kinetic curves of water vapor adsorption of buckwheat soup puree. At φ = 0.4, equilibrium humidity occurs on day 6–7, and at φ = 0.6 – on day 7. At φ = 0.8, the adsorption process lasts up to 19 days, and then desorption processes occur.

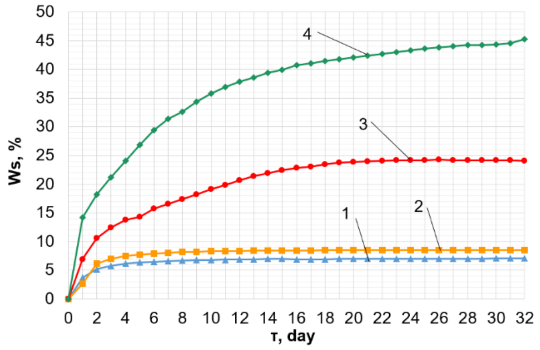

Fig. 3. Kinetic curves of water vapor adsorption of mashed pea soup (convenience food): 1 – φ = 0.4; 2 – φ = 0.6; 3 – φ = 0.8; 4 – φ = 0.9

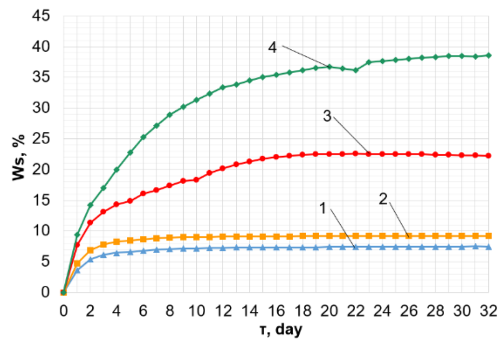

Fig. 4. Kinetic curves of water vapor adsorption, buckwheat soup puree (convenience food): 1 – φ = 0.4; 2 – φ = 0.6; 3 – φ = 0.8; 4 – φ = 0.9

The kinetic curves of water vapor adsorption of oatmeal-carrot porridge with milk are shown in Fig. 5. As can be seen from the figure, the equilibrium moisture content at φ = 0.4; 0.6 occurs on day 7, and at φ = 0.8 – on day 13, and at φ = 0.9 – on day 28.

The equilibrium moisture content of pumpkin porridge with milk (Fig. 6) at the value of φ = 0.4; 0.6 occurs on day 6. For the value of φ = 0.8 – on day 12, and for φ = 0.9 – continues to increase on day 32.

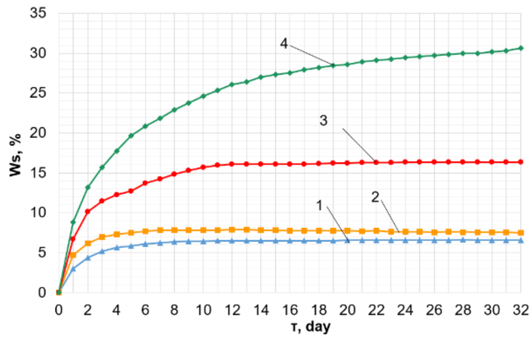

Fig. 5. Kinetic curves of water vapor adsorption, oatmeal-carrot porridge with milk (instant food): 1 – φ = 0.4; 2 – φ = 0.6; 3 – φ = 0.8; 4 – φ = 0.9

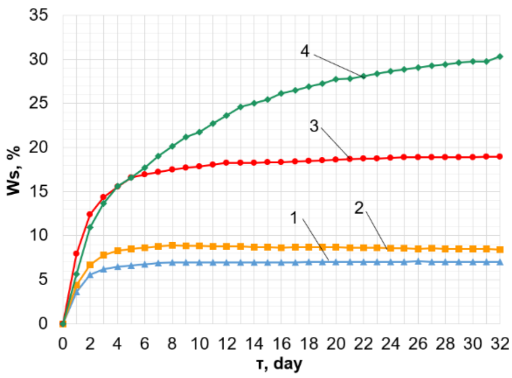

Fig. 6. Kinetic curves of water vapor adsorption, pumpkin porridge with milk (instant food): 1 – φ = 0.4; 2 – φ = 0.6; 3 – φ = 0.8; 4 – φ = 0.9

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Based on the experimental data on the equilibrium moisture content, water vapor adsorption isotherms of functional powders and instant foods based on them were constructed.

Figure 7, a shows the water vapor adsorption isotherms of carrot, pea, functional pea and carrot powder, and pea and carrot soup puree. Functional pea and carrot powder is the main ingredient in the pea and carrot puree soup recipe.

The equilibrium moisture content (Fig. 7, b) at φ = 0.4 of all the studied samples is in the range of 6–7 %. The lowest value of equilibrium moisture is found for functional pea and carrot powder at φ = 0.8–15 %, and at φ = 0.9–24 %. The isothermal curve of pea and carrot puree soup (position 4) is located between the curve of pea powder (position 3) and the curve of carrot powder (position 1).

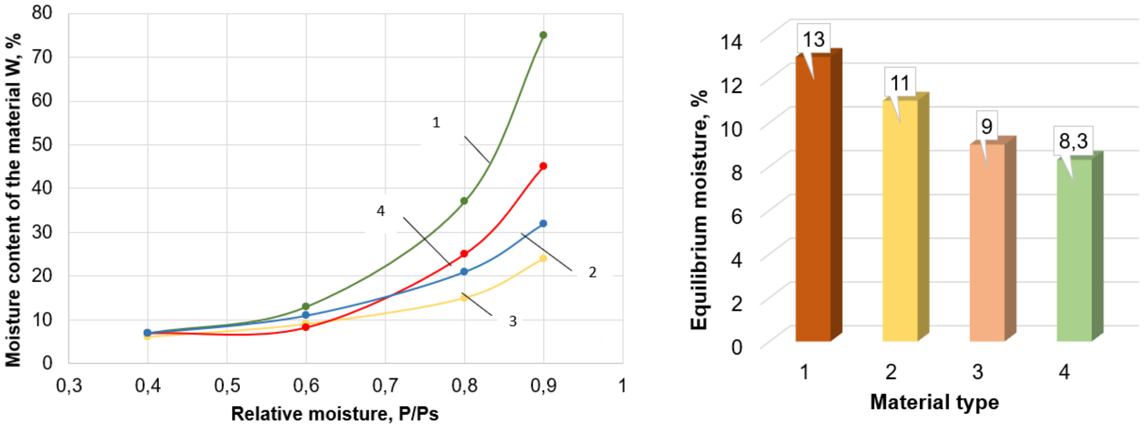

Fig. 7. Isotherms of water vapor adsorption (a) and equilibrium moisture content at φ=0.6 (b) of mono-, combined powders and instant foods based on them: 1 – carrot; 2 – pea; 3– pea and carrot; 4 – pea and carrot soup puree

The water vapor adsorption isotherms of carrot, buckwheat powders, and buckwheat soup-puree are shown in Fig. 8, a. The isotherm curve of buckwheat soup-puree (position 3) is located between the curves of carrot (position 1) and buckwheat (position 2) powders. At φ = 0.4, the equilibrium moisture content for all samples is almost the same and amounts to 7–8 %. At φ = 0.8, the equilibrium moisture content for buckwheat powder is 18 %, and at φ = 0.9–27 %. For buckwheat and carrot puree at φ = 0.8 it is about 22 %, and at φ = 0.9–38.5 %.

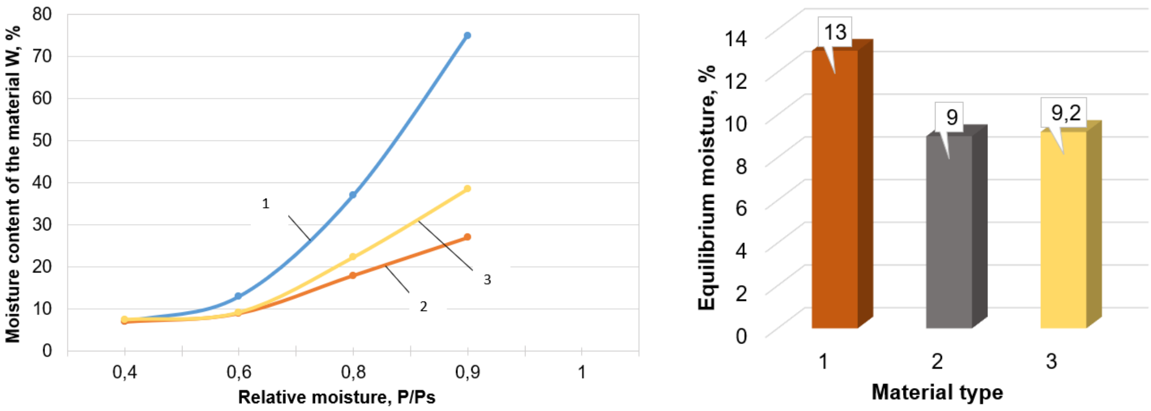

Fig. 8. Isotherms of water vapor adsorption (a) and equilibrium moisture content at φ=0.6 (b) of mono-, combined powders and instant foods based on them: 1 – carrot; 2 – buckwheat; 3 – buckwheat puree soup

A comparative characterization of the equilibrium moisture content of carrot, buckwheat powders, and buckwheat soup puree is shown in Fig. 8, b and is 13.9 and 9.2 %, respectively.

We also studied the adsorption characteristics of instant foods with milk powder in the recipe - oatmeal-carrot porridge with milk and pumpkin porridge with milk.

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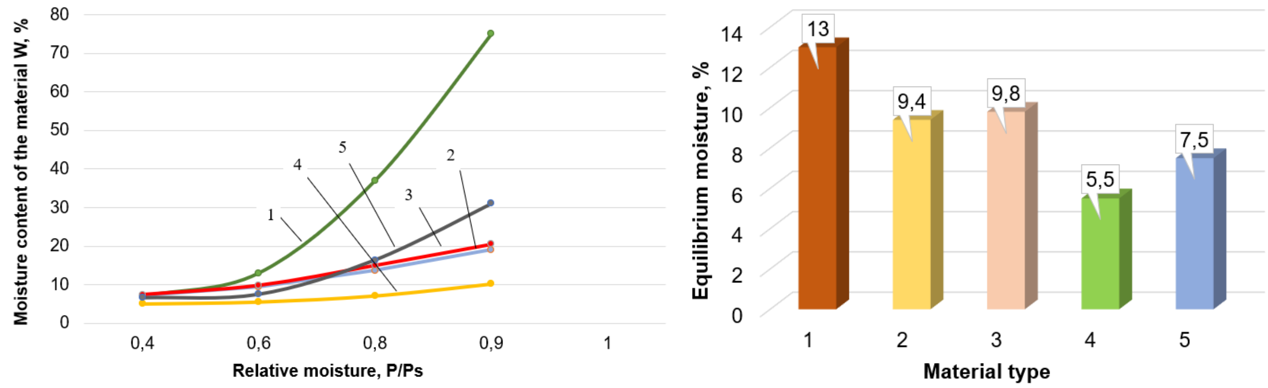
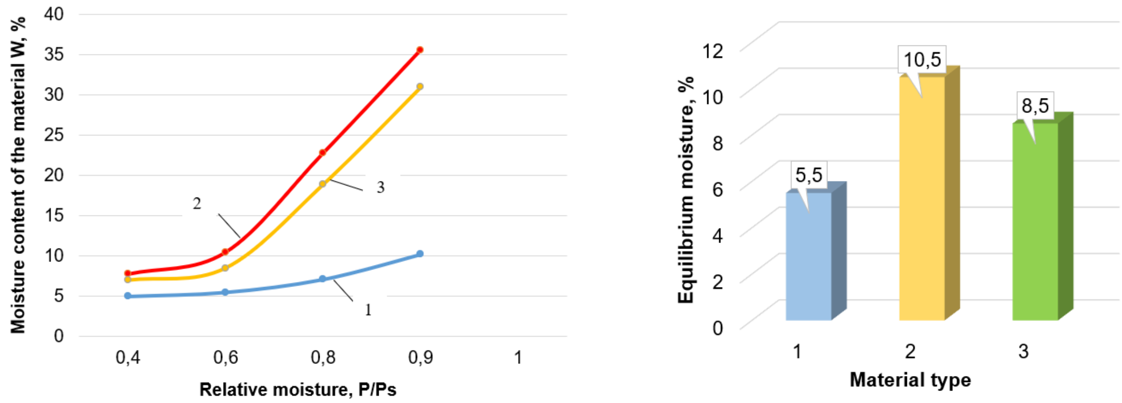


a b

Fig. 9. Isotherms of water vapor adsorption (a) and equilibrium moisture content at φ=0.6 (b) of mono-, combined powders and instant foods based on them: 1 – carrot; 2 – oatmeal; 3 – oatmeal-carrot; 4 – milk powder; 5 – oatmeal-carrot porridge with milk

Fig. 9, a shows the water vapor adsorption isotherms of carrot, oatmeal, oatmeal-carrot, milk powder, and oatmeal-carrot porridge with milk based on them. At φ = 0.4, the equilibrium moisture content of the samples under study is in the range of 5.0–7.5 %. At φ = 0.8, the equilibrium moisture content of carrots is 37 %, oatmeal powder 13.7 %, functional oatmeal-carrot 15 %, and oatmeal-carrot porridge with milk 16.4 %. The curve of the oatmeal-carrot porridge with milk (position 5) is located between carrot (position 1) and functional oatmeal-carrot (position 3) powders.

Figure 9, b shows a comparative characteristic of the equilibrium moisture content of the tested samples at φ = 0.6, which shows that oatmeal-carrot porridge with milk has a lower equilibrium moisture content of 7.5 % compared to oatmeal and functional oatmeal-carrot powder.



a b

Fig. 10: Isotherms of water vapor adsorption (a) and equilibrium moisture content at φ=0.6 (b) of mono-, combined powders and instant foods based on them: 1 – milk powder; 2 – pumpkin; 3 – pumpkin porridge with milk

The water vapor adsorption isotherms of pumpkin porridge with milk and its main ingredients are shown in Fig. 10, a. The highest equilibrium moisture content of pumpkin powder is 7.8 % at φ = 0.4, 23 % at φ = 0.8, and 36 % at φ = 0.9.

The main ingredient in instant cereal is pumpkin powder. The isotherm curve of pumpkin porridge with milk has a similar character to the isotherm curve of pumpkin powder. The equilibrium moisture content of the porridge at φ = 0.4 is 7 %, at φ = 0.8–18.9 %, at φ = 0.6– 8.5 %, at φ = 0.9– 31 %.

The equilibrium moisture content of pumpkin porridge with milk and its main ingredients at φ = 0.6 is shown in Fig. 0, b. As can be seen from the figure, pumpkin porridge has a lower moisture content of 8.5 % compared to pumpkin powder of 10.5 %.

Comparing the water vapor adsorption isotherms of instant foods (Fig. 11), it can be seen that at φ=0.4, dry oatmeal-carrot porridge with milk has the lowest equilibrium moisture content of 6.6 %, and buckwheat soup puree has the highest 7.5 %; at a relative humidity value of φ=0.6, oatmeal-carrot porridge with milk has the lowest value of 7.5 %, and buckwheat soup puree has the highest value of 9.2 %; at φ=0.8, the lowest value is for oatmeal-carrot porridge with milk 16.4 %, and the highest is for buckwheat soup-puree 22.3 %; at φ=0.8, the lowest value is for pumpkin porridge with milk and oatmeal-carrot porridge with milk 31 %, and the highest is for pea soup-puree 45 %.

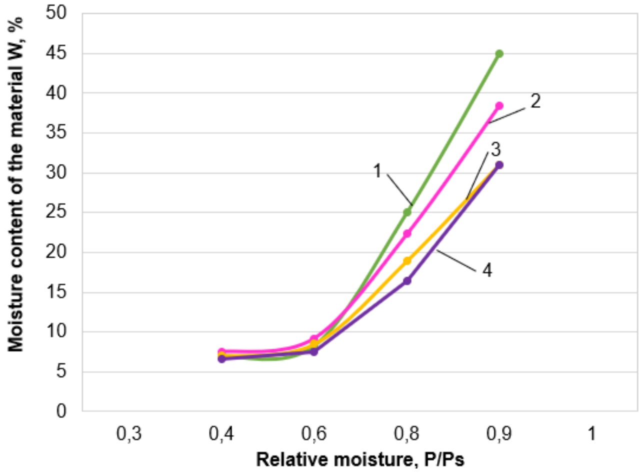


Fig.11. Water vapor adsorption isotherms of instant foods: 1 – Pureed pea soup; 2 – Pureed buckwheat soup; 3 – Pumpkin porridge with milk; 4 – Oatmeal-carrot porridge with milk

Thus, despite the same nature of the isotherms of the samples under study, which show that these materials are capillary-porous colloidal bodies and have the same forms of moisture binding (adsorption, capillary and osmotic), they differ significantly in equilibrium moisture content. This can be explained by their different biochemical composition.

The prospect of using convenience foods lies in the fact that they retain their properties for a long time and do not require special storage conditions.

Conclusions

The actual shelf life should be planned to match the shelf life of the entire product. The shelf life of food products is usually determined based on commercial requirements, taking into account the time required to deliver the product to the consumer, temperature conditions during the period from production to sale. A realistic estimate of the shelf life can only be obtained as a result of research and compliance with storage requirements. The shelf life should reflect the temperature and humidity conditions in which these products will be stored. It is important to conduct research on the temperature and humidity conditions in which food plant functional powders and dry instant foods based on them will be stored.

In Ukraine, the room temperature is 22–25 °C, and the relative humidity for this temperature is 60–70 %. Therefore, the adsorption properties of combined plant powders were investigated in order to select optimal storage conditions.

Due to the experimental studies of adsorption properties and comparative characterization of samples of mono-, functional powders and dry instant foods based on them, the equilibrium moisture content for each sample was determined. Mono-powders have the highest equilibrium moisture content. When they are combined to create functional powders, this ability decreases, which leads to improved storage conditions, and the equilibrium moisture content of instant foods is in most cases lower than that of functional powders.

When storing composite powders and dry instant foods based on them, in order to preserve their technological properties, it is recommended to maintain the following conditions in the room: air humidity 60–70 % at a temperature of 20–25 °C and to pack them hermetically.

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