ХАРЧОВА БЕЗПЕКА ТА ЕКСПЕРТИЗА ХАРЧОВИХ ПРОДУКТІВ

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APPLICATION OF PHYSICAL AND MATHEMATICAL METHODS AT THE EXAMINATION OF DRY BREAKFAST FOODS

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The object of the study is the breakfast cereals from different manufacturers. The aim of the article is to prove the possibility of using physical and mathematical methods for studying the dispersed composition of breakfast cereals during their commodity and customs examinations and expanding the possibilities of exporting these products based on assessing their quality.

Key words: *dry breakfast foods, commodity examination, differential distribution functions of pores by radius*

ЗАСТОСУВАННЯ ФІЗИКО-МАТЕМАТИЧНИХ МЕТОДІВ ПІД ЧАС ЕКСПЕРТИЗИ СУХИХ СНІДАНКІВ

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Об'єктом дослідження є сухі сніданки від різних виробників: «Nesquik» ТМ «Nestle», "«Lion» ТМ «Lion», «Duo Balls» ТМ «Doctor Benner», «Start» ПрАТ «Lantmannen», «Mr. Croco» ПрАТ «Дніпропетровський комбінат харчових концентратів». Метою статті є доведення можливості застосування фізико-математичних методів дослідження дисперсного складу сухих сніданків під час їх товарознавчих і митних експертиз.

Дослідженнями макропористої структури зразків сухих сніданків від різних виробників встановлено, що найбільш наближену до монодисперсної структуру має зразок «Duo Balls». Він має найменший розкид у значеннях радіусів макропор та найменшу дисперсію функції розподілення макропор за радіусами – 0.881. Зразок «Lion» відрізняється від зразка «Duo Balls» не суттєво, дисперсія його диференціальної функції розподілення макропор за радіусами, яка дорівнює 0.948, відрізняється на 8 %. Далі йдуть зразки «Start» (D(r)=1.082) та «Mr. Croco» (D(r)=1.131). Найбільш віддалену від монодисперсної структуру має зразок «Nesquik» (D(r)=1.333), дисперсія якого відрізняється на 51 % від зразка «Duo Balls».

За ізотермами сорбції досліджуваних зразків сухих сніданків від різних виробників встановлено значення відносної вологості оточуючого газового середовища, за якої можливе тривале зберігання цієї продукції без суттєвих змін якості. Ці значення відносної вологості для сухих сніданків становлять, %:

«Nesquik» – 68; «Lion» – 67; «Duo Balls» – 70; «Start» – 71; «Mr. Croco» – 62. За відносної вологості оточуючого газового середовища, яка перевищує ці значення, тривале зберігання можливе лише у газонепроникному упакуванні.

За диференціальними функціями розподілу мікропор за радіусами встановлено, що найменший розкид мікропор за радіусами має зразок «Mr. Croco», а найбільший – «Duo Balls». Зразки «Nesquik», «Lion» та «Start» займають проміжне положення.

Відзначено, отримані результати є об'єктивними показниками якості сухих сніданків, які можуть бути використані під час товарознавчої та митної експертизи цієї продукції.

Ключові слова: *сухі сніданки, товарознавча експертиза, функція розподілення пор за радіусами*

Problem statement in general terms. An important place in the agro-industrial complex of Ukraine is occupied by the grain industry, which includes industries engaged in the processing of grain crops: flour and cereal, food and feed.

Ukraine occupies a leading position in terms of the volume of cultivation and export of many agricultural crops: sunflower oil, sunflower seeds, rapeseed, corn, wheat, barley. Exports of agro-food products from Ukraine in January-June 2025 amounted to 11.3 billion USD [1]. The main sales markets for domestic agricultural products remain three regions - the countries of the European Union, Asia and Africa [2]. Their total share amounted to 92% of the value of Ukrainian agricultural exports. However, it should be noted that this is 9% less than last year's indicators for the corresponding period [3, 4].

The importance of domestic cereal production for the food security of the state and the peculiarities of the development of this market are devoted to a number of scientific works by Ukrainian researchers [5–7]. In the vast majority of these works, devoted to the consideration of the outlined issues, there is an analysis and discussion of the development trend of the cereal market in terms of supply formation, the degree of state intervention in pricing and the integration of Ukraine into the world economic space.

Analysis of recent research and publications. Among the range of cereal production products, such food concentrates as breakfast cereals should be highlighted [8].

Breakfast cereals have long become an integral part of the diet of a large number of people around the world. Convenience, minimal time consumption and a variety of tastes – all this determines their popularity. Recently, due to the awareness of the need for healthy eating and the accelerated pace of life, the population of Ukraine has also begun to prefer instant cereals and breakfast cereals [9].

The use of breakfast cereals goes beyond simple nutrition; they are convenient meal solutions, appealing to people who lead active and health-conscious lifestyles.

Breakfast cereals are products that are used by the population to quickly satisfy hunger «on the go» or for pleasure. Breakfast cereals are products made from corn, wheat, rice and other crops in the form of sticks, flakes, air grains, rings, stars, pillows, etc., which are consumed with milk, yogurt or another product that suits the taste. To improve the taste properties of the mixture, sugar syrup, caramel, nuts, dried fruits, pieces of chocolate are added, and the mixture is often enriched with vitamins and mineral salts of calcium, phosphorus, iron [10].

The global breakfast cereal market size was estimated at 40.3 billion USD in 2023 and is projected to reach 52.58 billion USD by 2031, growing at a CAGR of 3.38% from 2024 to 2031 [11].

The future of the global breakfast cereal market looks promising, with expected growth driven by increasing consumer demand for healthy, organic and high-protein options. Innovations in flavor profiles, packaging and sustainable practices are expected to further enhance the attractiveness of the market, given changing food preferences and environmental considerations.

The breakfast cereal market in Ukraine is saturated and can offer a wide range of products, both domestically and internationally produced, to the potential consumer [12]. A large share of the market is occupied by foreign brands, the production of which is located in Ukraine. It should be noted that the increase in consumption of products produced by national manufacturers is limited by the presence on the market of a large number of foreign analogues, which consumers prefer due to their reputation and quality. That is, Ukraine, having a sufficient raw material base, produces an insufficient amount of such products as breakfast cereals. The reason for this is that when consumers choose breakfast cereals, the determining factor is to a greater extent the reputation of the brand gained through high quality. Based on this, the development directions of domestic manufacturers, obviously, need to be adjusted in view of increasing the quality of the products obtained to a level not lower than the quality level of well-known foreign brands. This, obviously, will make it possible to satisfy domestic consumers and compete with well-known foreign brands on the international market. The main objective characteristics that provide an assessment of the quality of such products as breakfast cereals are organoleptic and physicochemical indicators. It should be noted that information on such physical indicators as hygroscopic properties, porosity, dispersed composition, as well as their compliance with regulatory documentation is not fully provided. At the same time, it should be noted the relevance of expanding the application of physical methods of quality assessment and mathematical methods of processing the obtained experimental data during commodity and customs examination of breakfast cereals.

The aim of the article is to prove the possibility of using physical and mathematical methods for studying the dispersed composition of breakfast cereals during their commodity and customs examinations and expanding the possibilities of exporting these products based on assessing their quality.

Materials and methods. The object of the study is the breakfast cereals «Nesquik» TM «Nestle» (hereinafter «Nesquik»), «Lion» TM «Lion» (hereinafter «Lion»), «Duo Balls» TM «Doctor Benner» (hereinafter «Duo Balls»), «Start» PrJSC «Lantmannen» (hereinafter «Start»), «Mr. Croco» PrJSC «Dnipro Food Concentrates Plant» (hereinafter «Mr. Croco»). The breakfast cereal «Nesquik» is a product of foreign production. The breakfast cereals «Lion», «Duo Balls», «Start» are products of a foreign manufacturer with production facilities in Ukraine. The breakfast cereals «Mr. Croco» are products of a Ukrainian manufacturer.

The macroporous structure was determined by microphotographs of the internal structure of the studied products. Microphotographs were taken using a HiView X4 1600X digital microscope.

The gyroscopic properties of the studied products were determined by the strain gauge method.

Description of the main research material. One of the determining indicators of the quality of breakfast cereals is their internal structure. The internal structure determines, firstly, such a consumer quality indicator as the appearance of the product, namely, the external surface. Secondly, it determines the properties of breakfast cereals to absorb water from a gaseous environment and under the condition of their wetting. At the same time, the hygroscopic properties of this dried product, i.e. the ability to give off or absorb water from the surrounding gaseous environment, are determined by the microporous structure of the studied systems. And the appearance of such products as breakfast cereals and the properties to absorb water under the condition of wetting are determined by their macroporous structure.

The study was conducted in two stages. At the first stage, the macroporous structure of breakfast cereals was studied, and at the second stage, the microporous structure.

When studying the external surface and macroporous structure of breakfast cereal samples, the initial data were microphotographs obtained using a digital microscope. The products under study are glazed – samples of breakfast cereals that have a spherical shape, covered with a layer of caramel.

Based on this, photographs of the external surface and a flat section of the samples were taken. The photographs obtained in this case are shown in Fig. 1 and Fig. 2.

From the photographs of the external surface, it can be seen that the surface of the sample «Mr. Croco» is more heterogeneous (Fig. 1 e). On the surface of this sample, there are inflows that can be identified by differences in their color, with sizes of 2…3 mm. The surface of other samples (Fig. 1 a–d) is visually more homogeneous with irregularities that do not exceed 400…500 μm.

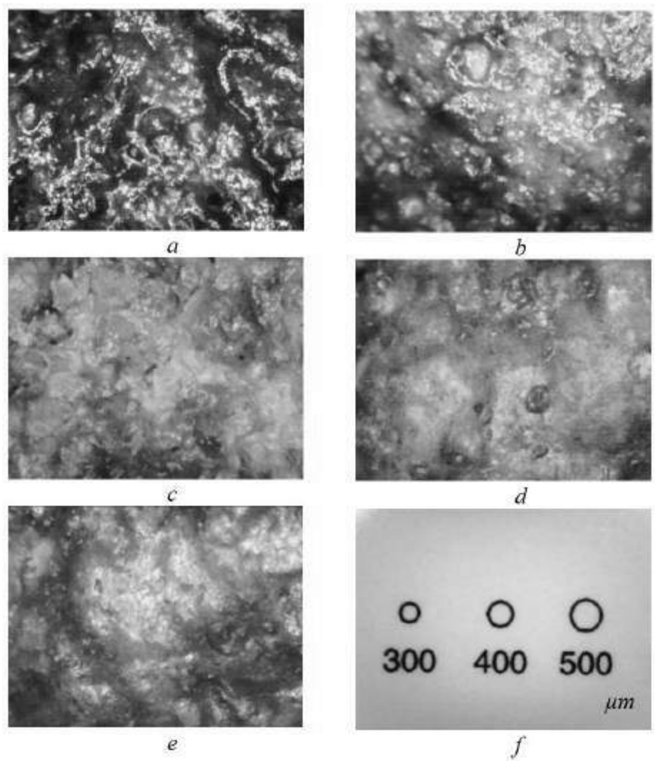

Fig. 1. Microphotographs of the rating scale (f) and the outer surface of samples of breakfast cereals from different manufacturers: a – «Nesquik»; b – «Lion»; c – «Duo Balls»; d – «Start»; e – «Mr. Croco»

In order to identify the causes of the presence of inhomogeneities on the outer surface of breakfast cereal samples, their flat section surface was examined (Fig. 2). At the same time, the structure of the samples was studied. The structure here means the differences in the sizes of the macropores that the samples under study contain. The sample, which macropores differ less in size from each other, was considered more homogeneous. Macropores mean pores visible to the «naked eye», that is, visible without the use of magnifying optical devices. The size of such pores is in the range of 200…1000 μm.

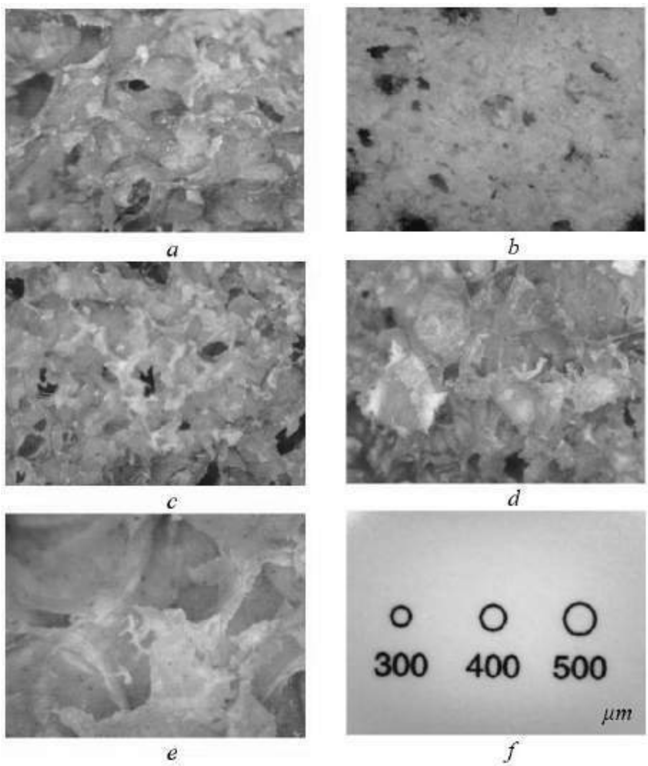

Fig. 2. Micrographs of the evaluation scale (f) and the surface of a flat section of samples of breakfast cereals from different manufacturers: a – «Nesquik»; b – «Lion»; c – «Duo Balls»; d – «Start»; e – «Mr. Croco»

Obviously, an objective assessment of the homogeneity of the structure of such porous systems, which are the studied samples of breakfast cereals, is provided by the analysis of the distribution of macropores by radii in them.

The distribution of macropores by radii in the studied samples of breakfast cereals was obtained by a statistical method.

From the micrographs of the surface of a flat section of each of the studied samples, the number of macropores N_1, N_2, N_3, … N_n, was calculated, which in size are, respectively, in the $[0, a)$; $[a, 2\cdot a)$; $[2\cdot a, 3\cdot a)$ … $[n\cdot a, (n+1)\cdot a)$. In this case, the value of the parameter a was equal to – 50 μm.

The total number of counted macropores N was found as:

$$N=N_1+N_2+N_3+\ldots+N_n. \tag{1}$$

The number of macropores for each of the N_i ranges (where i varies from 1 to n) was normalized to the total number of macropores and the relative number of macropores whose radius is in the i-th range was obtained.

A histogram was constructed using the obtained data, where the abscissa axis plotted the ranges of macropore radii, and the ordinate axis plotted the relative number of macropores for each range. The envelope of such a histogram is the differential function of the distribution of macropores by radii for the studied sample.

The analytical form of the envelope, which is the differential function of the distribution of macropores by radii for the studied samples of breakfast cereals, was found by approximating the experimental points with a function of the form:

$$f(r)=a\cdot r^b\cdot exp(c\cdot r), \tag{2}$$

where a, b, c – approximation coefficients.

Fig. 3 shows the differential distribution functions of macropores by radii for the studied samples of breakfast cereals. Table 1 shows the values of the approximation coefficients for these differential distribution functions.

Table 1

Approximation coefficients of the differential distribution function of macropores by radii for samples of breakfast cereals from different manufacturers

Sample	*a*	*b*	*c*
«Nesquik»	0.918	6.361	-2.127
«Lion»	32.563	4.063	-2.772
«Duo Balls»	14.539	7.966	-3.652
«Start»	0.758	8.909	-2.948
«Mr. Croco»	$3.208\cdot10^{-6}$	23.218	-4.81

Using the differential distribution function, the average radius of the micropores of the studied sample was found by the formula:

$$<r>=\int r\cdot f(r)dr. \qquad (3)$$

The most probable radius r_{pr} of the macropores corresponds to the maximum of the differential distribution function. Based on this, the numerical value of the radius was determined by the roots of the first derivative of the differential distribution function.

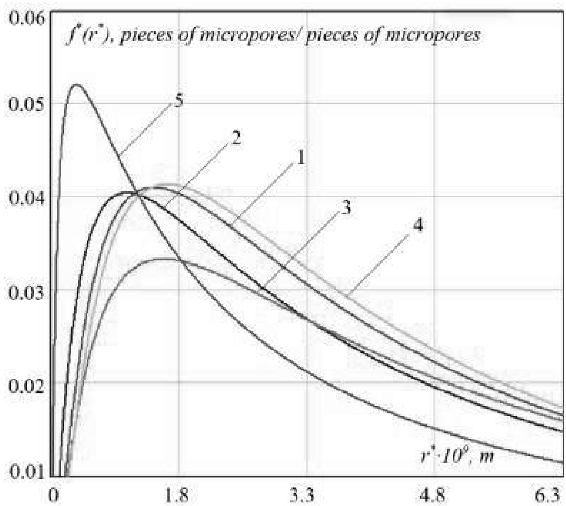

Fig. 3. Differential distribution functions of macropores by radii for samples of breakfast cereals from different manufacturers: 1 – «Nesquik»; 2 – «Lion»; 3 – «Duo Balls»; 4 – «Start»; 5 – «Mr. Croco»

Дисперсія диференціальної функції розподілу макропор за радіусами визначалась за формулою:

$$D(r)=\int(r-\langle r\rangle)^2\cdot f(r)dr. \tag{4}$$

The variance of the differential distribution function of macropores by radii was determined by the formula:

$$D(r)=\int(r-\langle r\rangle)^2\cdot f(r)dr. \tag{4}$$

The variance of the differential distribution function of macropores by radii was chosen as a criterion for assessing the homogeneity of the macrostructure of the studied samples of breakfast cereals. Dispersion in probability theory and mathematical statistics is a parameter for assessing the dispersion of a quantity by its probability. In the case of the differential distribution function of macropores by radii, it was chosen to assess the dispersion of macropores by radii. Obviously, the macrostructure of the sample should be considered closer to monodisperse, that is, one that consists of macropores of the same radius, provided that the variance of the differential distribution function of macropores of the studied sample is smaller.

The variance of the differential distribution functions, the most probable and average radii of the macroporous structure of the studied samples of breakfast cereals are given in Table 2.

Table 2

Variance *D(r)* of the differential distribution function, average $\langle r\rangle$ and most probable macropore radius r_{pr} of breakfast cereal samples from different manufacturers

Sample	$\langle r\rangle\cdot10^6$, m	$r_{pr}\cdot10^6$, m	$D(r)$
«Nesquik»	378	299	1.333
«Lion»	207	150	0.948
«Duo Balls»	263	219	0.881
«Start»	359	306	1.082
«Mr. Croco»	517	486	1.131

From the form of the differential distribution functions of macropores by radii for the studied samples, it is clear that in the studied range (from 50 to 700 μm) they are unimodal, that is, they have one extremum. This extremum corresponds to the most probable value of the radius of the micropores of the sample rim. The differences in the nature of the obtained distribution functions lie in the difference in the values of the most probable and average radius and the dispersion of these functions, and, accordingly, in the different dispersion of macropores by radii in the studied samples.

Based on the value of the dispersion of the differential distribution function of macropores by radii, the sample «Duo Balls» has the structure closest to monodisperse. It has the smallest dispersion in the values of the radii of macropores. The dispersion for this sample is 0.881. The next sample is the «Lion», the dispersion of which differs from the «Duo Balls» sample by 8% ($D(r)$=0.948), which can be considered an insignificant difference. The samples «Start» ($D(r)$=1.082) and «Mr. Croco» ($D(r)$=1.131) follow. The most distant from monodisperse structure is the «Nesquik» sample ($D(r)$=1.333), the dispersion of which differs by 51% from the «Duo Balls» sample, which has a structure closest to monodisperse.

The «Nesquik» sample has the most heterogeneous structure of the studied breakfast cereal samples, however, the average and most probable macropore radii are smaller compared to the sample with the largest radii «Mr. Croco». The average radius of the «Nesquik» sample is 1.37 times smaller compared to the average radius of the «Mr. Croco», and the most probable one is 1.63 times smaller. Based on this, although the sample «Mr. Croco» has a structure closer to monodisperse compared to the sample «Nesquik», however, the larger average and most probable radii, compared to other samples, cause pronounced irregularities that are visually observed on its surface (Fig. 1).

It should be noted that the distribution of macropores by radii in the studied samples mainly determines the appearance of breakfast cereals. As for the ability to absorb liquid when wetting, here the influence of the distribution of macropores by radii is limited by the fact that the surface of the studied breakfast cereals is covered with glaze. Based on this, the penetration of liquid into the macropores is limited during the time required for the glaze to dissolve.

However, regarding the absorption of water in the gaseous state, glaze is not an obstacle. The characteristic, which is an assessment of the property of dried products, such as breakfast cereals, to absorb water in a gaseous state from the surrounding environment, is the sorption isotherm [13].

The sorption isotherms were obtained by the tensometric method. Samples of breakfast cereals weighing 3…4 g were placed in desiccators with different relative humidity of the gaseous environment in them. The relative humidity in the desiccators was discretely changed from 10 to 90% in steps of 10%.

The samples were periodically weighed until they reached equilibrium moisture content. Then the values of the equilibrium moisture content of the sample at the corresponding relative humidity (sorption isotherms) were constructed. The sorption isotherms obtained for breakfast cereals from different manufacturers are shown in Fig. 4.

It should be noted that all the studied samples had a low initial moisture content, which did not exceed 6…8·10-2 rel. units (kg water/kg dry matter). Based on this, for the studied samples only sorption of water vapor from the surrounding gaseous environment created in the desiccator was observed.

The nature of the sorption isotherms for all the studied samples is similar. There are two sections: a section corresponding to polymolecular moisture sorption, and a section corresponding to moisture absorption by micropores. These sections differ in different inclinations of the sorption isotherms to the axis on which the relative humidity of the surrounding gaseous environment is plotted. It should be noted that the sorption isotherms of the studied samples do not have a section corresponding to monomolecular sorption.

The polymolecular sorption area can be separated from the area corresponding to moisture absorption by micropores by their linear approximation, as shown in Fig. 4. The boundary between these areas corresponds to the limit of relative humidity, above which it is not recommended to store the studied product for a long time. If the relative humidity of the environment increases relative to this limit value, water is absorbed by micropores and the samples swell. This leads, firstly, to the disappearance of such an organoleptic indicator of the quality of breakfast cereals as crispness, and, secondly, to the acceleration of oxidation and microbiological spoilage of this product during storage.

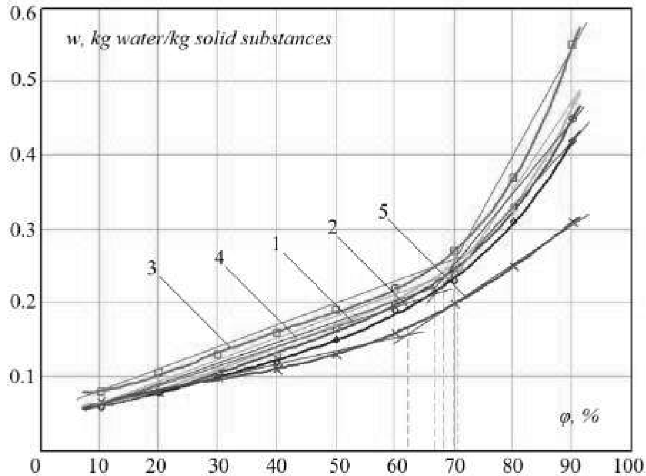

Fig. 4. Sorption isotherms of breakfast cereal samples from different manufacturers: 1 – «Nesquik»; 2 – «Lion»; 3 – «Duo Balls»; 4 – «Start»; 5 – «Mr. Croco»

For the studied samples, the boundary between the polymolecular sorption area and the area corresponding to moisture absorption by micropores is as follows, %: «Nesquik» – 68; «Lion» – 67; «Duo Balls» – 70; «Start» – 71; «Mr. Croco» – 62. Based on the results obtained, it is possible to formulate the storage conditions of breakfast cereals: their long-term storage is possible at the relative humidity of the gas environment, which corresponds to the boundary between the polymolecular sorption area and the area corresponding to moisture absorption by micropores. At the relative humidity of the surrounding gas environment, which exceeds this limit value, long-term storage is possible only in gas-tight packaging.

The reason for this nature of the sorption isotherms is obviously the different microporous structure of the studied breakfast cereal samples. To analyze the microporous structure of the studied breakfast cereals, differential distribution functions of micropores by radius were obtained.

The method of obtaining differential distribution functions of micropores by radius is described in detail in [14, 15]. It is based on the approximation of sorption isotherms by a function of the form:

$$\varphi = \frac{w^{A_3}}{A_1 + A_2 w^{A_3}}, \tag{5}$$

where A_1, A_2, A_3 – approximation coefficients; w – moisture content.

Using approximation coefficients, a differential distribution function of micropores by radius is obtained, which has the following form:

$$f_n(r^*) = \frac{1}{\sqrt{2\pi}\sigma_R R^*} exp\left(-\frac{(ln(R^*)-m_R)^2}{2\sigma_R^2}\right), \quad (6)$$

where m_R and σ_R – the parameters of the logarithmic normal distribution; R^* – the dimensionless radius of the micropore $R^* = (r^* - d_0)/d_0$; r^* – the radius of the micropore, m; d_0=0.3·10^{-9} m – the radius of the water molecule.

Differential distribution functions of micropores by radii for samples of breakfast cereals from different manufacturers are shown in Fig. 5. Table 3 shows the average and most probable micropore radius calculated from the obtained differential distribution functions [14, 15].

Table 3

Average $<r^*>$ and most probable r^*_{pr} micropore radius of samples of breakfast cereals from different manufacturers

Sample	$<r^*>\cdot 10^9$, m	$r^*_{pr}\cdot 10^9$, m
«Nesquik»	10.4	1.5
«Lion»	13.8	1.2
«Duo Balls»	13.9	1.6
«Start»	9.5	1.7
«Mr. Croco»	6.3	0.6

Differential distribution functions (Fig. 5) have one extremum, while differing in the values of the micropore radii corresponding to these extrema and the line width, and, accordingly, the average micropore radius (Table 3). The samples «Nesquik», «Lion» and «Start» have a similar line width. The «Mr. Croco» sample has the smallest line width, and the «Duo Balls» sample has the largest. The line width indicates the size of the micropore dispersion by radii, i.e. the larger the line width, the more micropores with different radii the sample holds. As a result, a more developed microporous structure contributes to a greater amount of moisture that such a system can absorb from the surrounding gas environment. This is the reason why the isotherm of the «Duo Balls» sample lies higher, and the isotherm of the «Mr. Croco» sample lies lower compared to the other studied samples relative to the moisture content axis. That is, the sample «Duo Balls» absorbs the largest amount of moisture from the surrounding gas environment, and the sample «Mr. Croco» the smallest. This result indicates that, obviously, the sample

«Duo Balls» loses such an organoleptic indicator inherent in breakfast cereals as crispness, at lower values of the relative humidity of the surrounding environment, compared to other samples. As for the sample «Mr. Croco», given its sorption isotherm, it retains crispness at values of the relative humidity of the surrounding environment that are higher compared to other studied samples of breakfast cereals. This is a significant consumer advantage compared to other samples.

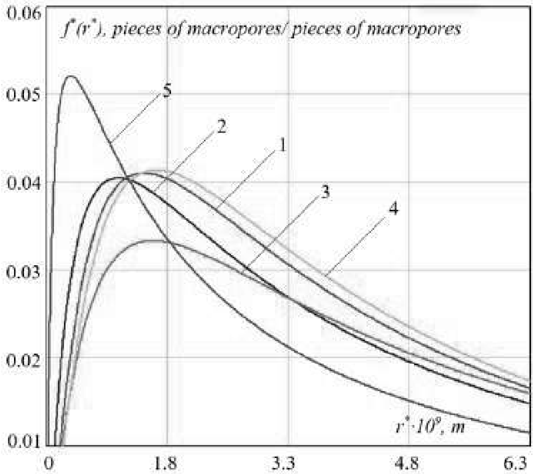

Fig. 5. Differential distribution functions of micropores by radius for samples of breakfast cereals from different manufacturers:
1 – «Nesquik»; 2 – «Lion»; 3 – «Duo Balls»; 4 – «Start»;
5 – «Mr. Croco»

It should be noted that although the sample «Mr. Croco» has the largest average and most probable radius of macropores (Table 2), it has the smallest average and most probable radius of micropores (Table 3) compared to other studied samples. This indicates that the study of the distribution of pores by radii, which determine the structure of such porous systems as breakfast cereals, does not provide complete information with one method. It follows that in order to obtain a complete picture of such a functional and technological property as porosity, it is necessary to use at least two different research methods.

Thus, the results obtained prove that the sample of breakfast cereals «Mr. Croco», in terms of porous structure, is not inferior to products of foreign manufacturers, and in terms of hygroscopic properties it even has advantages in terms of storage requirements.

The results obtained are obviously objective indicators that characterize the micro and macro porosity of breakfast cereals. They were obtained by physical and mathematical methods used in scientific research in the food and processing industry. It should be noted that the results obtained by fundamental methods are more acceptable compared to the results obtained by express methods, which are most often used during commodity and customs examinations.

The limitation of the conducted research is the incomplete commodity expertise of the studied breakfast cereals. The disadvantage of the research is the limited range of the studied products. Expanding the range of breakfast cereals is a potential prospect for further research.

Conclusions. Studies of the macroporous structure of breakfast cereal samples from different manufacturers have shown that the sample «Duo Balls» has the structure closest to monodisperse. It has the smallest spread in the values of macropore radii and the smallest dispersion of the macropore distribution function by radii – 0.881. The sample «Lion» does not differ significantly from the sample «Duo Balls», the dispersion of its differential macropore distribution function by radii, which is 0.948, differs by 8%. The samples «Start» ($D(r)$=1.082) and «Mr. Croco» ($D(r)$=1.131) are next. The sample «Nesquik» ($D(r)$=1.333) has the structure furthest from monodisperse, the dispersion of which differs by 51% from the sample «Duo Balls».

It is noted that the distribution of macropores by radius in the studied samples mainly determines the appearance of breakfast cereals. As for the ability to absorb liquid when wetting, here the influence of the distribution of macropores by radius is limited by the fact that the surface of the studied breakfast cereals is covered with glaze. Based on this, the penetration of liquid into the macropores is limited during the time required for the dissolution of the glaze. It is noted that with regard to the absorption of water in the gaseous state, glaze is not an obstacle. The characteristics that assess the property of dried products, such as breakfast cereals, to absorb water from the surrounding gaseous environment are sorption isotherms.

From the sorption isotherms of the studied samples of breakfast cereals from different manufacturers, the value of the relative humidity of the surrounding gaseous environment at which long-term storage of this product is possible without significant changes in quality was determined. These values of relative humidity for breakfast cereals are, %: «Nesquik» – 68; «Lion» – 67; «Duo Balls» – 70; «Start» – 71; «Mr. Croco» – 62. If the relative humidity of the surrounding gas environment exceeds these values, long-term storage is possible only in gas-tight packaging.

According to the differential distribution functions of micropores by radius, it was found that the sample «Mr. Croco» has the smallest spread of micropores by radius, and the largest – «Duo Balls». The samples «Nesquik», «Lion» and «Start» occupy an intermediate position. It was noted that due to the more developed porous structure, the sample «Duo Balls» absorbs the largest amount of moisture from the surrounding gas environment, and the sample «Mr. Croco» the smallest, compared to other studied samples. It was noted that as a result, the sample «Duo Balls» loses such an organoleptic indicator inherent in breakfast cereals as crispness, at lower values of the relative humidity of the surrounding environment, compared to other samples. It was noted that the sample «Mr. Croco», given its sorption isotherm, retains crispness at values of the relative humidity of the surrounding environment that are higher compared to other studied samples of breakfast cereals. This is a significant consumer advantage compared to other samples.

The results obtained prove that the sample of breakfast cereals «Mr. Croco» of the Ukrainian manufacturer PrJSC «Dnipro Food Concentrates Plant», in terms of porous structure, is not inferior to the products of foreign manufacturers, and in terms of hygroscopic properties it has advantages in terms of storage requirements.

It is noted that the results obtained are objective indicators of the quality of breakfast cereals, which can be used during commodity and customs examinations of these products.

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