

UDC 664.8.047

RESEARCH AND DEVELOPMENT OF HEAT TECHNOLOGY OF
PREBIOTIC COMPLEX-FORMING POWDER PRODUCTIONSniezhkin Yu. F.¹, Academician of the National Academy of Sciences of Ukraine, Petrov P. I.², postgraduate¹*Institute of Engineering Thermophysics of NAS of Ukraine, 2a, Marii Kapnist Str., Kyiv, Ukraine, 03057, <https://orcid.org/0000-0002-9049-3392>, email: itf_ntps@ukr.net*²*Institute of Engineering Thermophysics of NAS of Ukraine, 2a, Marii Kapnist Str., Kyiv, Ukraine, 03057, <https://orcid.org/0009-0006-0632-3558>, petrov.mriya@gmail.com*<https://doi.org/10.31472/tpe.2.2024.3>

The process of dehydration of the prebiotic squash-apple mixture is investigated, taking into account the properties of the material and drying modes. Prebiotic raw materials are maximally represented by dietary fibers, which include pectin substances, the content of which in raw materials is from 6 to 12%. Optimal modes of grinding and separation into different fractions of dry prebiotic materials for obtaining functional powders were determined. The complexing property of prebiotic mixtures is determined, which is 15-20% higher than pure pectin, due to an increase in the open surface of powders and the nativity of pectin substances.

Досліджено процес зневоднення пребіотичної кабачково-яблучної суміші з урахуванням властивостей матеріалу і режимів сушіння. Пребіотична сировина максимально представлена харчовими волокнами, до яких відносяться пектинові речовини, вміст яких в сировині становить від 6 до 12 %. Визначено оптимальні режими подрібнення і розділення на різні фракції сухих пребіотичних матеріалів для отримання функціональних порошків. Визначено комплексуючу властивість пребіотичних сумішей, яка на 15 – 20 % вища, ніж чистого пектину, завдяки збільшенню відкритої поверхні порошків та нативності пектинових речовин.

Bibl. 8, fig. 5, table 1.

Key words: convective drying, grinding, separation, complexing property, prebiotic raw materials, functional products, food powder.

Introduction. One of the common and easy to implement methods to prevent food spoilage, improve safety, facilitate processing and extend shelf life is the drying process [1, 2]. Dehydration not only reduces moisture content and water activity, but also significantly minimizes decay processes caused by the growth of bacteria, yeast and mold.

Dry foods have a wide range of uses, including instant foods, spices added to soups and sauces, muesli and healthy snacks such as fruit and vegetable chips, which have gained popularity recently [3, 4].

Convective drying is the most commonly used process, thanks to several advantages such as a simple dryer and a known drying mechanism [5].

Development of new efficient heat technologies solves the problem of rational use of raw materials, fuel and energy resources [4]. This has not only a scientific, but also a social aspect, because at the same time the scientific foundations of a rational diet are formed and, accordingly, the quality of life is increased [6,7].

The interaction of the elements of the triad "man - technology - nature" is very far from harmony. The forceful influence of the first two components on the third leads to irreversible confrontation: nature responds with destructive spontaneous cataclysms, methodical work on the corrosion of metal parts of technical products, the introduction into the human body (through the respiratory organs and food intake) of substances harmful to it.

The hostilities that take place on the territory of Ukraine lead to pollution of territories, air, soils with heavy metals, which, together with food, enter the human body and lead to various diseases [7].

The creation of preventive and therapeutic products of this direction is based on the concept of introducing food impurities into their formulation that meet the following requirements: safety for the body and effective binding of heavy metals (the formation of strong insoluble complexes with them that are resistant to enzymes in a wide range pH) [8].

To some extent, these requirements are met by food polysaccharides, which are in prebiotic functional powders.

Problem statement is complex and effective processing of plant raw materials into prebiotic combined powders of high biological value. Study of the process of dehydration of the zucchini-apple composition taking into account the properties of the material and drying modes. Determination of optimal modes of grinding dry prebiotic material and dividing it into different fractions to obtain functional powders. Prebiotic powders are characterized by high complexing ability due to the high content of pectin substances.

Determination of radioprotective properties of zucchini-apple powder in comparison with pure pectin preparations.

Purpose of work and setting research objectives. The purpose of the work is effective drying and experimental justification of the dependence of the maximum yield of highly dispersed prebiotic powder on the speed of rotation of the chopper rotor and the separation time to determine the complexing ability of these powders.

Methods of researches. During the research, experimental methods were used using modern means of measuring drying parameters: the time of the experiment, the temperature of the coolant and the reduction of the mass of the material with the help of automated systems for collecting and processing information in the developed programs "Sooshka", and "Cooler" on specially designed and manufactured installations. Methods of mathematical planning of the experiment were used for processing experimental data, and the obtained data were processed in modern integrated systems Excel and Mathcad.

Standard research spectroscopy, electron microscopy methods were used to assess the quality of functional products. Theoretical studies conducted using methods based on the main provisions of the theory of heat and mass transfer, the theory of similarity, which were processed using computer technology.

Presentation of the main material and scientific results. The article presents the results of the influence of the coolant temperature on the drying kinetics of prebiotic raw materials based on zucchini and apple. Two parts of fresh zucchini combined with one part of apple [4].

These products were cut into 5x5 mm cubes, mixed and a certain solution was taken for further experiment. The change in moisture content in the prebiotic raw material, for a certain period of time, to moisture 4-6% does not differ from other types of drying of functional raw materials.

Figure 1 shows the effect of the heat carrier temperature on the drying kinetics (a) and the drying rate (b) of the mixture of zucchini with apple.

As can be seen from the figure, the drying of the mixture takes place during the period of falling rate. At the heat carrier temperature 100 °C, the duration of drying to moisture 4-6% is 2.1 times less, than at the heat carrier temperature 60 °C, and the maximum rate is 1.7 times more.

But, taking into account our previous studies on the effect of temperature on the quality and content of pectin substances in the prebiotic material, which showed that at a temperature of more than 60 °C the gelling property of pectins in the material decreases, therefore drying of samples for the study of grinding, separation and their complexing ability was carried out at a heat carrier temperature of 60 °C [4].

Prebiotic food powders obtained as a result of dispersion consist of a large number of particles and are subject to statistical laws. Experimental studies of these processes have shown, that the distribution of particles by diameter in the aggregate is generally continuous with the presence of extremes. The results of the studies are presented in the form of differential and integral distribution curves, with the argument being the particle size δ , and the function is the content of particles of a given size, expressed by weight.

When constructing differential curves of mass distribution on the abscissa axis, the values of particle diameters are postponed - from the smallest $\delta_{\min}$ to the largest $\delta_{\max}$, and along the ordinate axis - the mass distribution function [4]:

$$F(\delta) = \frac{\Delta m}{Mp \cdot \Delta \delta}, \quad (1)$$

where Mp – total weight of all particles, g;

Δm – mass of particles in the range of sizes from δ to $\Delta \delta$, g.

For further use of the resulting zucchini-apple mixture, samples of the material were ground to a powdery state.

Grinding was carried out on a laboratory disintegrator at a rotor rotation speed of 30-80 m/s. Differential distribution curves of the zucchini-apple powder mixture depending on the rotor speed of the disintegrator showed that they have two maximum values and one minimum (Fig. 2).

The maximum values of the zucchini-apple powder mass distribution are at powder dispersity of 0.16 and 0.4 mm, and the minimum at 0.3 mm. The highest differential distribution of the powder mass from the zucchini-apple

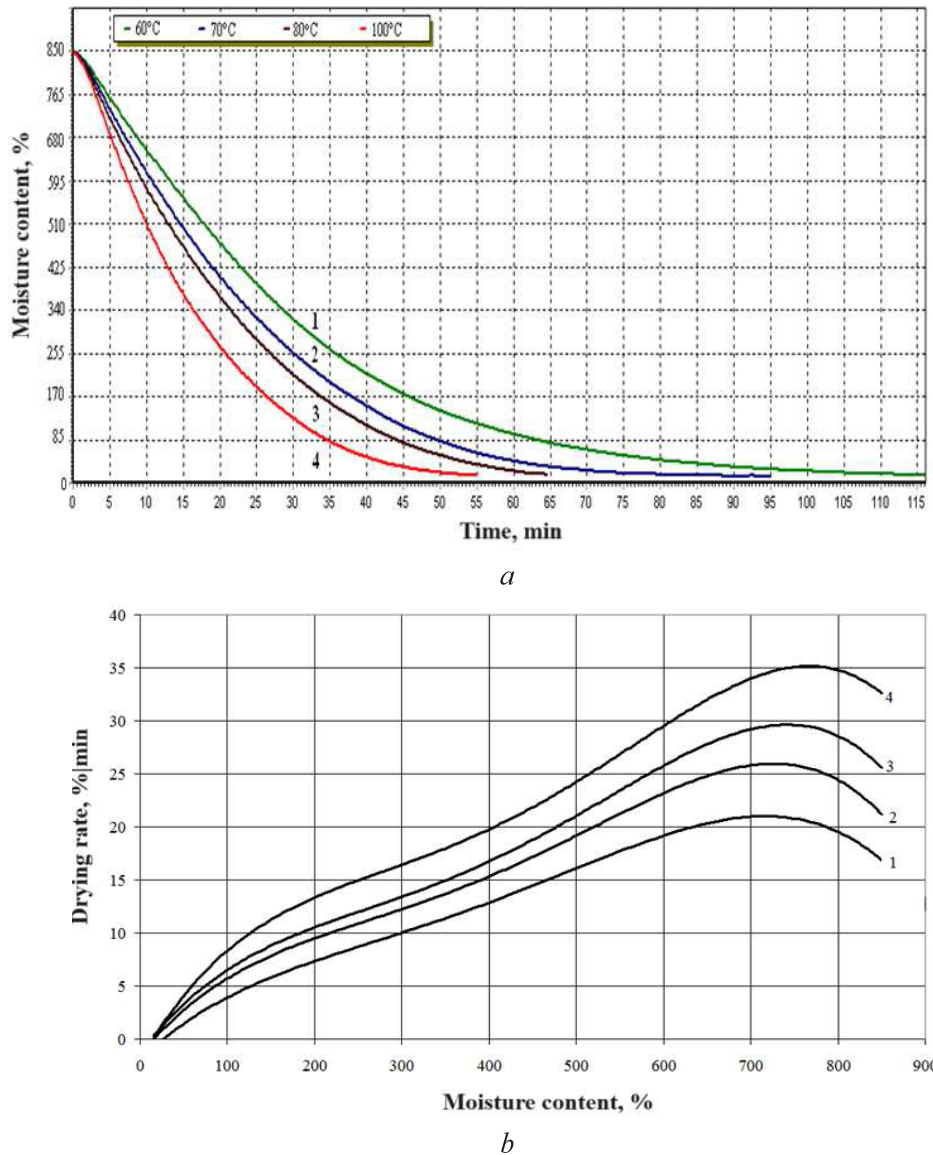


Fig. 1. Change in moisture content (a) and drying rate (b) of the prebiotic mixture of zucchini with apple (2:1) at different coolant temperatures ($\delta = 10$ mm at $W_{end} = 8$ %; $V = 3,5$ m/s; $d = 10$ g/kg dry air 1 – 60°C, 2 – 70 °C, 3 – 80°C, 4 – 100°C

mixture is observed with a powder size of 0.16-0.25 mm with a disintegrator rotor rotation speed of 80 m/s. This dimension refers to the finely dispersed. As can be seen from the integral powder weight distribution curves, the amount of powder weight (Fig. 3) at particle size < 0.25 mm is about 70%. Therefore, this fraction and its production modes are recommended for industrial production.

Research on the duration of grinding the zucchini-apple mixture (Fig. 4) showed that increasing the duration of the process from 3 min to 7 min at a rate of 80 m/s increases the output of the highly dispersed fraction by only 1.1%, and at a low speed of 30 m/s min, this difference is 25%.

Therefore, during the industrial production of this powder, it is sufficient to maintain the rotation rate of the disintegrator rotor at 80 m/min and a short duration of about three minutes.

Observations of the overall structure of the zucchini-apple powder using an electron microscope showed that it contains evenly distributed particles of zucchini and apple without agglomeration (Fig. 5). Since the amount of soluble carbohydrates in the mixture decreases, the particles of both apples and zucchini do not stick together (Fig. 5a).

The presented photos in Fig. 5 show how the structure of the combined squash-apple powder (b) differs from apple powder (c) with the same dispersion. Due to the high content

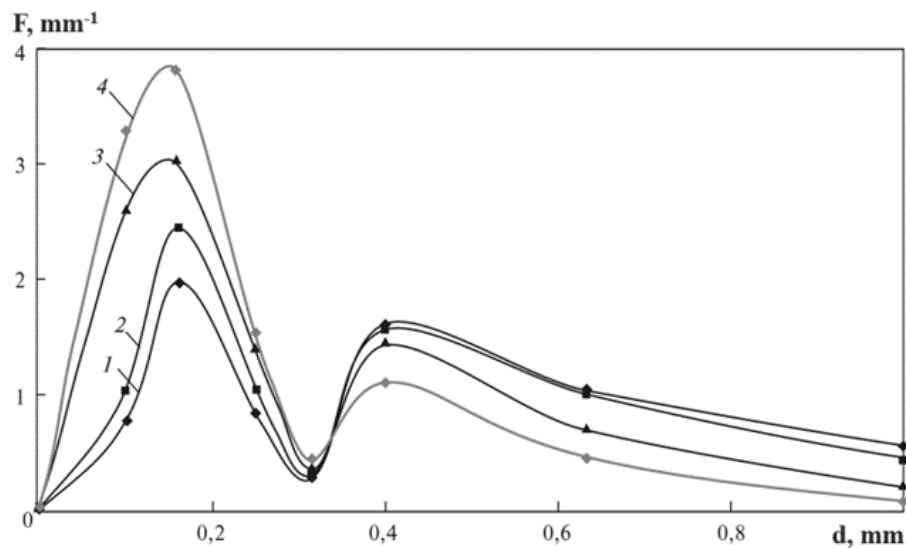


Fig. 2. Differential powder weight distribution curves with squash-apple mixture of particle size at speed rotation of the disintegrator rotors: 1 – 30 m/s, 2 – 50 m/s, 3 – 70 m/s, 4 – 80 m/s and sieving time 5 minutes, ratio of raw material components 2:1

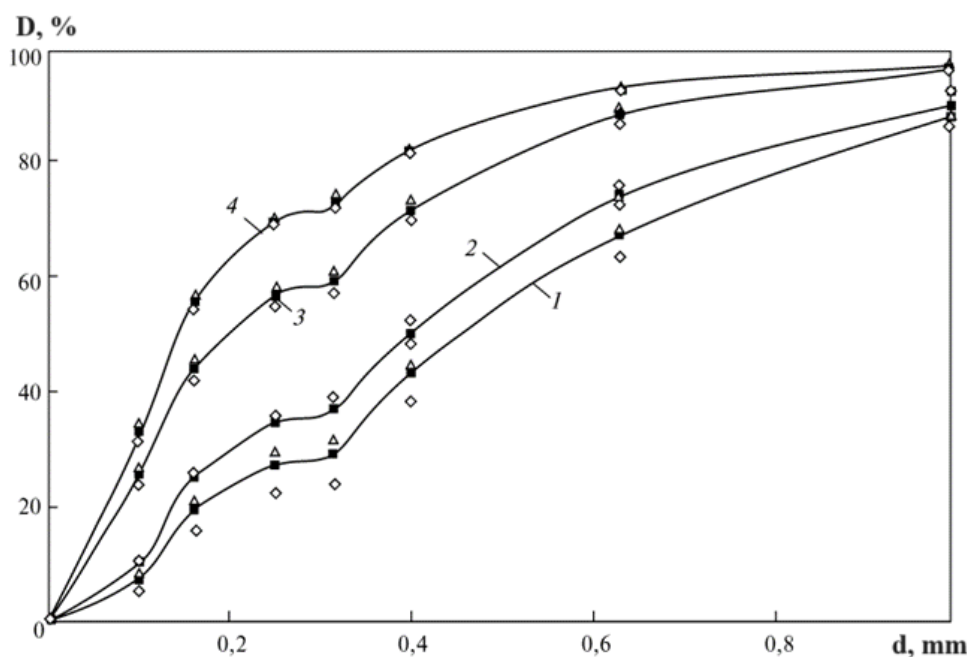


Fig. 3. Integral curves of the distribution of the mass of the zucchini-apple mixture powder from the particle size at the rotational rate of the disintegrator rotors: D, % d, mm

1 – 30 m/s, 2 – 50 m/s, 3 – 70 m/s, 4 – 80 m/s with a sieving time of 5 minutes with a component ratio of 2:1

of soluble carbohydrates, apple powder with a dispersion of 0.16-0.25 mm has the appearance of a continuous agglomerate, which makes it difficult to work with it.

Unlike mono, the combined powder does not contain agglomerates, so it has better structural and mechanical properties.

In food products, it is possible to use functional powders with a fraction of $d=0.5$ mm. Then the yield of powders is about 90% when the rotor rotates at 80 m/s (Fig. 3, 4) for about 3 minutes.

Pectin substances, which are found in the amount of 9-12 % in zucchini-apple powder, are part of dietary fibers

with the property of various positive physiological effects on the body, which refers them to prebiotics.

Prebiotic functional powders after grinding are a complex of dietary fibers, their content is up to 87%.

Thermal treatment of plant raw materials changes the activity of pectins. During the release of moisture in mild conditions, there is a rearrangement of those groups that ensure gelatinization and complexation.

We found in vitro, that 1 % powder solution binds ions of lead, cesium, zirconium. The following functional powders were studied: zucchini-apple, zucchini, apple. The determination of the complexing property was determined by the method given in the work [4].

The experiment is based on the complexing property of pectin. The solution of the metal salt of a given concentration

was contacted with an aqueous suspension of powders. By the difference between the introduced and the left metal, we find the percentage of metal binding.

As noted by other authors, the complexing property is predominantly pectins. Studies of complexing properties of prebiotic powders determined in vitro with different metals.

Pure apple pectin was used for comparison (Table 1). Powders and pectin were < 0.5 mm dispersed. Table 1 shows the complex-forming properties of functional powders with respect to lead, copper, zinc, zirconium, cesium. The analysis of Table 1 shows, that the prebiotic zucchini-apple powder binds heavy metal ions better, than apple pectin in all indicators. The 20 % lead, 9 % zirconium, 5 % cesium, 2 % zinc, 1 % copper. If we compare mono powders, apple powder is better than zucchini powder.

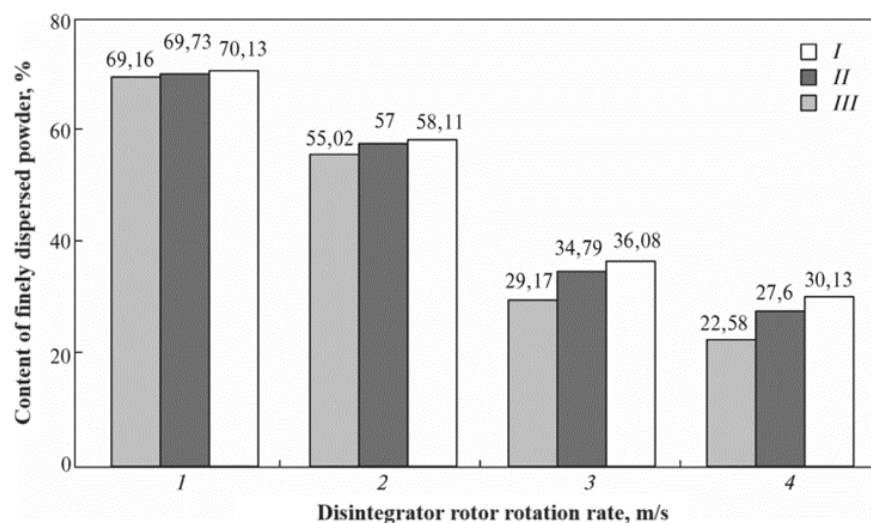


Fig. 4. Dependence of the yield of the highly dispersed fraction < 0.25 mm of pumpkin-apple powder on the speed of rotation of the disintegrator rotor (1 – 80 m/s; 2 – 70 m/s; 3 – 50 m/s; 4 – 30 m/s;) for different sieving times, min: I – 3; II – 5; III – 7 with a ratio of components of 2:1

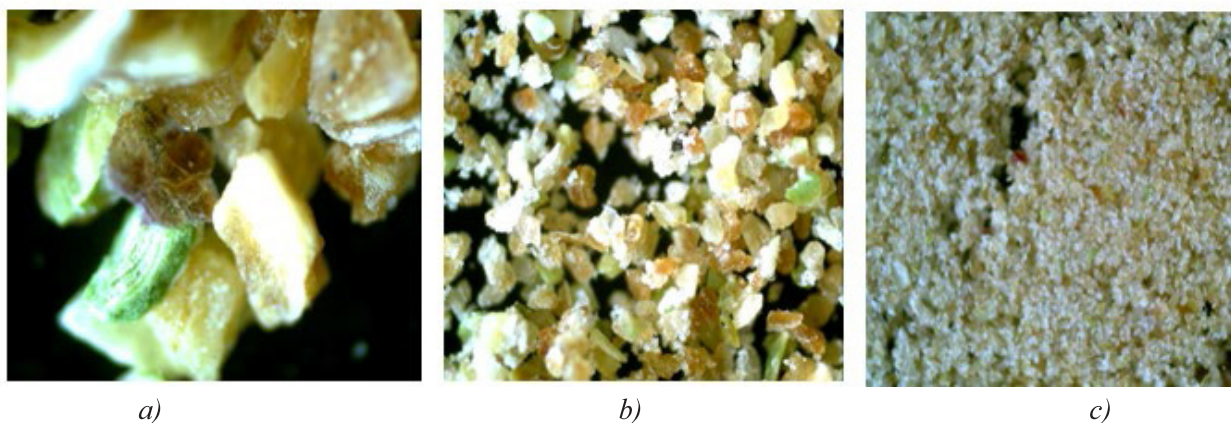


Fig. 5. Photographs of zucchini-apple powder on an electron microscope at a magnification of 400:1, fraction sizes: a) 0,63 – 1 mm; b) 0,16 – 0,25 mm; c) less than 0.1 mm

Table 1. Binding of heavy metal ions by prebiotic powders in vitro (% of the introduced amount of metals)

Metal	pH-binding	Apple pectin	Functional powders		
			Apple	Zucchini	Zucchini-apple
Lead	3,5-5,6	60	72	76	80
Copper	4,0-6,0	55	59	56	56
Zinc	3,5-6,0	67	73	66	69
Zirconium	2,0-3,5	53	67	50	62
Cesium	1,5-3,0	47	48	49	52

As can be seen from the table 1 complexing property of prebiotic zucchini-apple powder is 1-20% higher, than pure pectin. This can be explained by the fact, that prebiotic powders contain native pectin for the following 5 heavy metal ions. This is also due to the high fiber content in these powders.

Prebiotic zucchini-apple powder has a high content of pectins and has a complexing capacity of up to 80 %, and pure pectin 60 %, apple powder 72 %, zucchini 76 %.

Taking into account the fact that the binding of heavy metal ions by zucchini-apple powder reaches 50-80%, it is advisable to recognize their high radioprotective property.

Conclusions

On the basis of research, an energy-efficient mode of drying prebiotic zucchini-apple raw materials was developed.

Effective modes of dispersion and classification of functional powders have been developed, which, in comparison with monopowders, have better technological properties associated with an increase in dispersion and a decrease in agglomeration.

The complex-forming property of the functional researched materials was determined, which is 1-20% higher than that of pure pectin preparations, due to the increase in the open surface of the powders and the nativeness of pectin substances.

As a result of research, the modes of drying, dispersing, classification and separation are recommended for effective thermal technology of processing prebiotic raw materials into food-functional combined pumpkin-apple powder with high complexing properties for binding heavy metal ions.

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**ДОСЛІДЖЕННЯ І РОЗРОБКА
ТЕПЛОТЕХНОЛОГІЇ ОТРИМАННЯ
ПРЕБІОТИЧНОГО
КОМПЛЕКСОУТВОРЮЮЧОГО ПОРОШКУ**

Снєжкін Ю.Ф.¹, академік НАН України,
Петров П.І.², аспірант

¹Інститут технічної теплофізики НАН України, вул.
Марії Капніст, 2а, Київ, Україна, 03057, ittf_ntps@ukr.
net, <https://orcid.org/0000-0002-9049-3392>

²Інститут технічної теплофізики НАН України, вул.
Марії Капніст, 2а, Київ, Україна, 03057, petrov.mriya@
gmail.com

<https://doi.org/10.31472/ttpe.2.2024.3>

Сухі продукти харчування мають широкий спектр застосувань. Конвективне сушіння є найбільш часто використовуваним процесом, завдяки декільком перевагам, таким як нескладна сушарка і відомий механізм сушіння. Створення профілактичних та лікувальних сухих продуктів оснований на концепції розробки на їх основі функціональних сумішей. Введення їх в рецептуру харчування дозволить забезпечити організм захистом від негативного впливу навколишнього середовища. Цим вимогам відповідають харчові полісахариди, до складу до яких входять пектинові речовини, що знаходяться в пребіотичних функціональних порошках. В статті представлено дослідження процесу зневоднення розробленої пребіотичної кабачково-яблучної композиції з урахуванням властивостей матеріалу і режимів сушіння; визначено оптимальні режими подрібнення сухого пребіотичного матеріалу і розділення його на різні фракції для отримання функціональних порошків; визначено комплексують властивість пребіотичних сумішей, яка на 15...20 % вища, ніж чистого пектину, завдяки збільшенню відкритої поверхні порошків та нативності пектинових речовин.

Ключові слова: конвективне сушіння, подрібнення, розділення, комплексують властивість, пребіотична сировина, функціональні продукти, харчовий порошок. Бібл. 8, рис. 5, табл. 1.

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*Отримано 29.01.2024
Received 29.01.2024*

*Прийнято до друку 11.04.2024
Accepted for publication 11.04.2024*