DEVISING OPTIMAL TECHNOLOGICAL PARAMETERS FOR SPRAY DRYING TO PRODUCE WHOLE CAMEL MILK POWDER

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Camel milk is a valuable source of protein and nutrients, it has therapeutic and prophylactic properties. The production of dry dairy products based on camel milk implies prolonging its shelf life, a decrease in the cost of its transportation and storage. To manufacture dry camel milk, it is necessary to optimize the technological parameters of drying, which affect its physical-chemical properties.

Whole milk from camels (Camelus dromedarius) was dried on a spray drying plant under the following modes: the inlet temperature from 140 °C to 160 °C; the feed rate from 30 ml/min to 40 ml/min. The dependence of such physical properties of milk powder as the water solubility index, water absorption index, moisture content, hygroscopicity, density, water activity, the stickiness and size of particles on the technological parameters of drying has been established.

The study results show that the highest index of solubility of samples was equal to 81.25±0.11 %, which corresponded to the air temperature at the inlet of 150 °C and the feed rate of 30 ml/min. At the same time, the lowest solubility was 62.89±0.27 % under the modes of 140 and 40 ml/min, respectively. With an increase in the air temperature at the inlet and a decrease in the rate of supply of dairy raw materials, there was a decrease in the moisture content and water activity. However, an increase in the air temperature at the inlet above 150 °C led to a decrease in the solubility index in water. The optimal particle sizes of whole camel milk powder, preceding a relatively high solubility index, were 36.22±0.33 μm, 108.89±0.56 μm, and 229.19±0.74 μm.

The data reported in this paper could be useful in devising the technology for manufacturing a dry milk product from camel milk

Keywords: dry whole camel milk, spray drying, physical properties, production technology

1. Introduction

The basic raw material to produce dairy products in the world is cow's milk. However, many people suffer from intolerance to cow's milk protein, which could cause an allergic reaction in the body. In turn, camel milk, in its quantitative and qualitative protein composition and other biological properties, is close to breast milk and belongs to the so-called albumin group. The absence of allergies in the human body to camel milk is explained by good digestion of an easily digestible clot, which, under the action of enzymes, acquires the form of small flakes. It is also proved that camel milk has high therapeutic and prophylactic and dietary properties, owing to which it has wide medical indications for the use of products based on it.

Due to the presence of antimicrobial properties, raw camel milk has a slightly longer shelf life than cow's milk.

However, in order to preserve its biological and nutritional properties for a long time, it also needs to be processed. There are various methods for preserving milk in th world; all of them are based on the suppression of pathogenic microorganisms, preventing their further growth and development.

Drying is one of the common methods of milk preservation, in which free moisture is removed, as much as possible inhibiting the reproduction of microorganisms. An effective method of drying milk, in terms of the energy cost and output of finished products, is spray drying. In this case, the production of dry dairy products based on camel milk could not only expand the range of products but would also stimulate milk production and the growth of livestock at camel farms. On one hand, this could provide an impetus for the industrial introduction of export-oriented products with high added value, on the

other hand, for the development of the country's agro-industrial complex.

With the right choice of methods and parameters of drying, it is possible to obtain dry camel milk with a long shelf life and with maximum preservation of biological and nutritional properties. In this case, a special role belongs to the physical properties of the resulting powder as they predetermine the consumer qualities of the finished product. These physical properties include, among others, solubility, moisture content, hygroscopicity, density, water activity, the stickiness and size of particles. Therefore, devising the optimal technological parameters for the spray drying of camel milk, in order to obtain improved physical properties of the finished product, is a relevant task.

2. Literature review and problem statement

Paper [1] reports the results of research into the production of camel milk in the world, which amounted to about 5.3 million tons per year. Of them, 1.3 million tons are spent for direct consumption by people, and the rest is spent on feeding camel colts. This is due to the low volumes of processing of raw camel milk into dairy products – mainly due to the non-prevalence of processing technology. It was found that during lactation the average daily production of camel milk is from 3 to 10 liters. Under appropriate conditions (improvement of animal feeding ration, the availability of water, and proper veterinary care of animals), this figure can reach up to 20 liters [2]. The low productivity of camels in comparison with cows is compensated for by the chemical composition, biological and nutritional value, as well as the proven antimicrobial and immunomodulatory properties of camel milk.

It has been shown that, despite the relatively small amount of average daily milk yield, camel milk is a valuable source of nutrients. It contains volatile acids, especially linoleic acid, polyunsaturated and monounsaturated fatty acids, which have an important role in human nutrition [3]. They belong to the indispensable factors of nutrition as they are not formed in the body and must come from food. In addition, camel milk is a rich source of protein: lysozyme, lactoferrin, lactoperoxidase, immunoglobulins, etc. According to studies, the protein that defines peptidoglycans has been found only in camel milk. Camel milk contains low amounts of β-casein and lacks β-lactoglobulin, so it can be consumed by people suffering from allergies to cow's milk [4, 5]. Therefore, it could be used as a therapeutic and prophylactic agent and a full-fledged replacement of cow's milk in human nutrition.

It was found that the immunomodulatory property of camel milk is determined by the high content of vitamin C, which is three times higher than in cow's milk, and one and a half times higher than that in breast milk. It was determined that camel milk contains a large amount of minerals such as sodium, potassium, iron, copper, zinc, selenium, and magnesium [6], necessary to maintain the vital activity of the body. In addition, for people suffering from lactose intolerance, camel milk could be recommended since the lactose contained in it is easily metabolized [7]. These data show the advantages of camel milk compared to other types of milk, in particular, cow's milk. At the same time, it was noted in work [8] that the chemical composition of camel milk may differ depending on the regions of animal habitat. Thus, the fat and protein content in the milk from camels in Kazakhstan was 3.65 % and 3.59 %, while in the camel milk obtained from Australia it was 2.53 % and 2.97 %, respectively. The difference in the nutritional and biological value of camel milk is also explained by the diet of animals, the diversity of vegetation, and climatic conditions.

However, the issues related to the preservation of the initial quality indicators of camel milk over a long time remained not fully resolved. The reason for this may be the objective difficulties associated with the preservation of camel milk. A rational way to preserve the quality indicators, biological and nutritional value of milk, preceding the reduction of costs for storage and transportation of finished products, is drying.

Drying of milk in the production of dry dairy products is the process of removing free water from products, which is carried out in two stages – by condensing and drying pre-condensed products. Condensing the product is achieved by its evaporation to obtain 18–20 % of the mass fraction of casein-calcium phosphate complex in water; at the same time, the product should remain fluid. Despite the choice of drying technique, certain requirements for the physical properties of the product must be met during and as a result of the process. These include the specified final moisture content, free friability, the minimum content of free surface fat, the required fullness and rate of dissolution at the minimal losses of raw materials [9]. These properties must meet the standards as they determine the consumer qualities of the product.

It was established that there are various methods of milk drying: freeze-dried, convective, conductive, drum, etc. However, due to high energy costs and low production efficiency, not all types of drying are advisable to use in the production of milk powder. The best way to overcome the relevant difficulties may be to use spray drying. When spray drying in the flow of hot air and using a contact technique, there should not be overheating, drying, and burning of milk powder, as well as the phenomenon of adhesion and cohesion. The duration of stay of the material in the chamber should be a few seconds, in order to achieve high performance of the dryer at low energy costs. However, for some thermolabile materials, its use is undesirable due to the high-temperature level of the heat carrier, which, at the inlet to the dryer, is from 100 °C to 170 °C, and at the outlet – 50–95 °C. Therefore, in the production of dry camel milk by spray drying, the authors used an inlet temperature of 150 °C, which corresponded to the temperature of the finished product at the outlet of 94 °C. In addition, during spray drying, there are significant losses of the dried product due to its removal with the spent heat carrier [10].

In addition, one of the main tasks in the production of milk powder is to preserve the biological and nutritional value of the raw materials. This approach was used in work [11], whose authors indicated that as a result of drying camel milk, the qualitative composition of amino acids did not change while the quantitative content increased. In this case, the amino acid composition determines the nutritional and biological values of milk.

However, spray-drying camel milk when using the same temperatures and feed rates as cow's milk could lead to undesirable results. Thus, an increase in the temperature and rate of supply of dairy raw materials could lead to a

deterioration in solubility due to the Maillard reaction, and the decrease – to the growth of stickiness and the reduction in friability.

All this suggests that it is advisable to conduct a study on the optimization of the technological parameters of spray drying to manufacture dry camel milk with improved physical properties.

3. The aim and objectives of the study

The aim of this study is to optimize the technological parameters in the production of dry whole camel milk with improved physical characteristics and preservation of nutritional and biological value.

To accomplish the aim, the following tasks have been set:
– to work out the technological parameters of spray drying in the production of dry whole camel milk;
– to determine the physical characteristics of the dry whole camel milk obtained by spray drying;
– to treat the results mathematically to determine the optimal technological parameters of spray drying.

4. The study materials and methods

4 1. The study materials and equipment
The research materials were fresh whole camel milk and whole camel milk powder. The fresh whole camel milk (*Camelus dromedarius*) was obtained from the camel farm TOO Daulet-Beket, Akshi, Almaty oblast, Kazakhstan. The samples of camel milk were delivered in a thermal container; after delivery to the laboratory, they were stored in a refrigerator at a temperature of 4±0.5 ˚C.

We dried camel milk at the laboratory spray drying unit Buchi mini Spray Dryer B-290 (Switzerland).

In determining the solubility index and absorption of water samples, we used a vortex mixer (ZX4, Velp Scientifica, Italy), a centrifuge (Model 4200, Kubota, Japan), and a convection oven (ED 23, Binder Gmbh, Germany).

A digital hydrometer (Pro's Kit, NT-113, USA) was used to control and monitor the parameters in determining the hygroscopicity of samples.

We determined the density of the samples after shaking using a helicoidal pycnometer (Micromeritics Accu-Pyc II 1340, USA) by measuring 1.0±0.1 g of the sample.

The value of water activity in the samples was determined at a digital analyzer of water activity (Model 3TE, Aqualab, USA).

To measure the stickiness of the samples, a texture analyzer (TA-HT2, Stable Micro Systems, UK) was used.

The particle sizes of the samples and their distribution were determined at a laser diffraction particle size analyzer (Mastersizer 2000, Malvern, UK).

4. 2. Methods of studying the physical properties of dry whole camel milk
Determining the solubility index in water. The solubility of the samples was determined according to the procedures described by the author of work [12]. We poured 2.5 g of the sample in a graduated test tube of 50 ml, added 30 ml of distilled water, and stirred. Next, the test tube was put in a water bath (37 ˚C) for 30 minutes. Af-

ter incubation, the resulting mixture was centrifuged at 3,500 rpm for 30 min. The resulting liquid phase was poured into a pre-dried and weighed glass Petri dish. Then the Petri dish was put in a convection oven for drying at 105 ˚C for 24 hours. After drying, the Petri dish was removed from the oven and put in an exicator. The chilled Petri dish with sample residues was re-weighed until a constant weight was obtained. The residue was a solubilized powder; the weight of the residue by the initial mass of the sample was expressed as an indicator of solubility in water (*WSI*), which can be determined as follows:

$$WSI_{\%} = \frac{m_2}{m_1} * 100, \qquad (1)$$

where *WSI* is the water solubility index, %; m_1 is the initial mass of the sample, g; m_2 is the mass of residue after drying, g.

Determining the water absorption index. After centrifugation and separation of the liquid phase, the resulting sediment was weighed. The water absorption index (*WAI*) was calculated as the weight of the sediment in relation to the reference weight of the sample, which can be determined as:

$$WAI_{\%} = \frac{m_3}{m_1} * 100, \qquad (2)$$

where *WAI* is the water adsorption index, %; m_1 is the initial mass of the sample, g; m_2 is the sediment mass after centrifugation, g.

Determining hygroscopicity. Hygroscopicity is the ability of the dry powder to absorb moisture from the environment. One gram of milk powder was weighed in a pre-dried and weighed glass Petri dish and placed in a closed exicator at room temperature of 25±1 ˚C. The relative humidity of the medium inside the exicator was 75±2 %, which was maintained by 150 ml of a saturated solution of NaCl [13]. After seven days, the samples were removed and re-weighed. To determine the hygroscopicity of the sample, the weight difference between the reference and final sample was calculated per 100 g of dry matter (g/100 g) [14]:

$$H = \frac{(m_2 - m_1) * 100}{m_1 * \left(\frac{100 - W}{100}\right)}, \qquad (3)$$

where *H* is hygroscopicity, %; m_1 is the initial mass of the sample, g; m_2 is the final mass of the sample, g; *W* is the moisture content in the sample, %.

Determining bulk density. The bulk density was determined by measuring the mass of the powder sample at specified volumes. Each sample was carefully poured without sealing into a dry graduated cylinder with a volume of 25 ml, weighed, and registered [15]. This procedure was repeated 3 times for each sample. The value of the bulk density was determined as follows:

$$\rho_b = \frac{m}{V}, \qquad (4)$$

where: ρ_b is the bulk density of the sample, g/cm^3; *m* is the sample mass, g; *V* is the sample volume in the graduated cylinder, cm^3.

Determining density after shaking. The density after shaking was determined by measuring the mass per unit volume of powdery substances, excluding voids. For each sample of milk powder, the measurement procedure was carried out 3 times.

Determining water activity. 2 g of the sample was weighed in a cup and placed in a water activity meter. The activity of water in the sample was determined at room temperature of 25±1 °C. The results of the tests were calculated as an arithmetic mean of three repetitions [16].

Determining stickiness. The applied constant compression force used in the texture analyzer is 40 g, and the displacement height is 10 mm. 3 ml of glycerin is added to 2 g of the milk powder sample and stirred until a homogeneous state is formed. The resulting mixture is placed in the compartment for the sample, then, for 1 s, the probe of the device is in contact with it. The analyzer recalculates the value of the gravity at which the probe is separated from the surface of the mixture, which corresponds to the value of the stickiness of the sample [17].

Determining particle sizes. A sample of the milk powder was placed in the supply compartment of the device. Compressed air was fed to the analyzer, and the sample particles were moved to the laser chamber under vacuum conditions. Particle size values were calculated as diameter at 10 %, 50 %, and 90 % cumulative volume with a distribution curve constructed by the volumetric distribution over particlesize (µm) [18].

The results are presented as an average value±standard deviation. Statistical analysis was carried out using the Microsoft Excel software, Statistica 10. Reliable differences between the mean values of repeated measurements at each data point were analyzed using variance analysis, $P{\leq}0.05$.

5. The results of studying the physical properties of dry whole camel milk

5. 1. Testing the technological parameters of spray drying

To obtain finished products with certain physical indicators, it is necessary to find the optimal drying parameters. These parameters are factors that affect the resulting indicators such as the temperature at the inlet and the speed of raw material feed. The resulting indicators are the physical properties of the finished product. They include an outlet temperature, solubility index, absorption index, moisture content, hygroscopicity, bulk and post-shake density, water activity, stickiness, and particle sizes.

When making cow's milk powder using a spray drier, high temperatures at the inlet are applied, which usually vary from 170 °C to 220 °C. However, as discussed above, camel milk is a thermolabile product, so it is necessary to reduce the upper limit of the temperature used; to this end, the temperature at the inlet was initially set at 180 °C. When applying an inlet temperature of 170 °C and 180 °C (the feed rate was 35 ml/min), the resulting whole camel milk powder revealed unsatisfactory organoleptic characteristics (Fig. 1). The color of the sample included a pronounced yellow tint, the taste was bitter, the appearance and structure contained individual burnt particles.
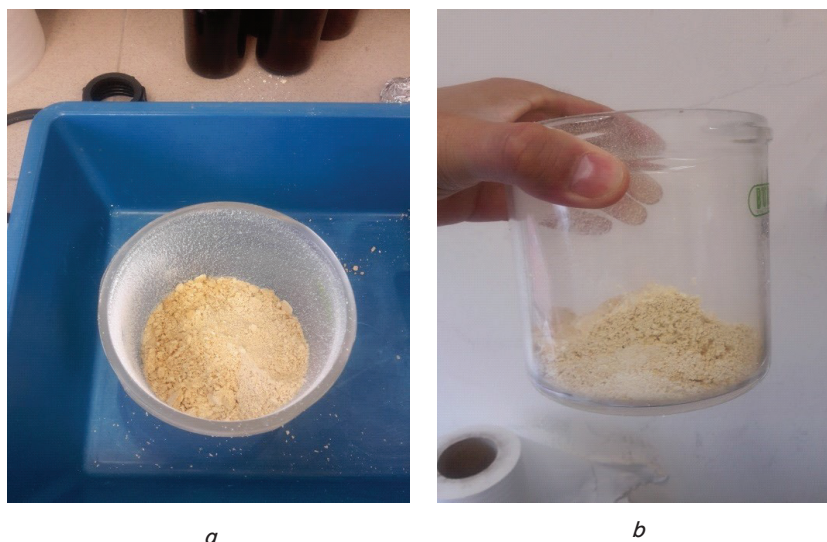

a   *b*

Fig. 1. Color of the sample of dry whole camel milk obtained at the following air temperature at the inlet: *a* — 170 °C; *b* — 180 °C

When the inlet temperature was below 140 °C, the resulting milk powder had undried fractions and high humidity. Based on the results of our experiments, it was found that in order to obtain dry whole camel milk with good physical and organoleptic indicators, the temperature at the inlet should be in the range from 140 °C to 160 °C.

The second factor in the study, affecting the properties of the finished product, was the speed of supply. The use of a feed rate below 30 ml/min led to partial burning of milk powder and slowing down the drying process. It should also be noted that the feed rate above 40 ml/min (at an inlet temperature of 140 °C to 160 °C) led to the increased moisture content in the finished product: the dairy raw materials did not have time to dry. Given the above, in further research, the feed rate of raw materials was in the range of 30 to 40 ml/min.

5. 2. Determining the physical indicators of dry whole camel milk

The physical properties of dry whole camel milk obtained by spray drying at an inlet temperature of 140 °C to 160 °C and a feed rate of 30–40 ml/min are given in Table 1.

According to the data in Table 1, the best indicators for the solubility index, absorption index, hygroscopicity, and particle size correspond to the inlet temperature of 150 °C at a feed rate of 30 ml/min. In terms of moisture content, water activity, hygroscopicity, bulk density, and density after shaking, the best results corresponded to the following parameters: inlet temperature, 160 °C; feed rate, 30 ml/min.

Table 1

Dependence of physical properties on the parameters of drying camel milk

Inlet temperature, °C (x_1)		140			150			160		
Feed rate, ml/min (x_2)		30	35	40	30	35	40	30	35	40
Outlet temperature, (y_0)		85	80	78	95	90	88	112	107	100
Solubility index, % (y_1)		71.44±0.18	67.42±0.15	62.89±0.27	81.25±0.11	72.33±0.25	64.28±0.18	65.59±0.21	73.35±0.31	68.22±0.14
Absorption index, % (y_2)		130.12±0.34	149.87±0.27	185.66±0.22	123.41±0.34	128.25±0.19	171.79±0.23	160.33±0.36	125.22±0.45	145.42±0.26
Moisture content, % (y_3)		3.05±0.09	3.55±0.07	4.05±0.08	2.44±0.04	2.72±0.05	2.95±0.09	2.25±0.11	2.57±0.21	2.81±0.18
Hygroscopicity, % (y_4)		23.19±0.24	25.55±0.21	24.97±0.27	16.29±0.31	18.81±0.35	21.71±0.22	19.98±0.36	20.09±0.41	23.32±0.54
Density,g/cm³ (y_5)	Bulk	0.389±0.03	0.392±0.03	0.372±0.07	0.455±0.05	0.433±0.04	0.353±0.08	0.554±0.05	0.454±0.08	0.467±0.09
	After shaking	0.655±0.11	0.675±0.09	0.644±0.08	0.751±0.07	0.722±0.06	0.604±0.04	0.803±0.09	0.787±0.12	0.744±0.08
Water activity (y_6)		0.302±0.06	0.337±0.08	0.401±0.05	0.237±0.05	0.254±0.08	0.272±0.09	0.193±0.04	0.196±0.05	0.230±0.03
Stickiness, g (y_7)		53.76±0.44	67.56±0.39	80.42±0.57	32.35±0.27	53.98±0.33	70.23±0.45	22.61±0.55	41.67±0.49	58.22±0.66
Particle size, μm (y_8)	$d(0.1)$	80.12±0.51	92.34±0.57	112.67±0.69	36.22±0.33	42.35±0.38	66.40±0.52	46.40±0.42	59.25±0.52	85.44±0.71
	$d(0.5)$	212.87±0.88	250.09±0.75	233.78±0.89	108.89±0.56	106.49±0.61	168.14±0.77	120.18±0.86	132.57±0.78	235.21±0.95
	$d(0.9)$	355.78±1.09	400.83±1.23	471.29±1.19	229.19±0.74	234.56±0.83	431.61±0.67	248.93±0.52	311.82±0.88	335.67±0.96

5. 3. Processing of experimental data and the mathematical substantiation of the choice of technological parameters for spray drying

To substantiate the choice of technological parameters used in the spray drying of camel milk to obtain the best indicators of the physical properties of the final product, the plots of factor correlation for each parameter are built.

Outlet temperature. An increase in the rate of supply of raw materials by 1 measurement unit leads to a decrease in the temperature at the output by an average of 0.867 measurement units. An increase in temperature at the inlet by 1 measurement unit leads to an increase in the temperature at the outlet by an average of 1.266 units. Based on the maximum coefficient, $\beta_2=0.935$, we conclude that the temperature factor at the outlet has the greatest influence on the result of the temperature at the outlet. The statistical significance of the equation was verified using the coefficient of determination and the Fisher criterion. It was found that in a given event, 97.61 % of the total temperature variability at the output is explained by a change in factors. It was also established that the parameters of the model are statistically significant (Fig. 2).

Water solubility index. An increase in the air temperature at the inlet by 1 measurement unit leads to a decrease in the solubility index by an average of 0.763 units. An increase in the feed rate of the raw materials by 1 measurement unit leads to an increase in the solubility index by an average of 0.0895 units. The statistical significance of the equation was verified using the coefficient of determination and the Fisher criterion. It was found that in the examined event, 35.89 % of the total variability of the solubility index is explained by a change in the factor of feed rate of raw materials. The response surface is shown in Fig. 3.

3D Surface: t, °C (inlet) vs. v, ml/min vs. t, °C (outlet)

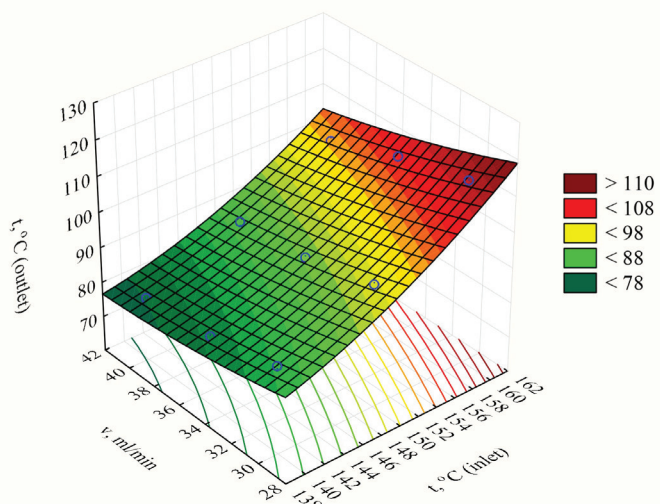t, °C (outlet) = 432,3056–5,8583*x+1,0167*y+0,0267*x*x–0,025*x*y+0,0267*y*y

Fig. 2. Response surface of the output temperature dependence on inlet temperature and feed rate

It follows from our calculations that the solubility index is more influenced by the feed rate of raw materials than the temperature of the raw material at the inlet. Fig. 3 demonstrates that the optimal temperature regime for the solubility index is the range of 142–150 °C at a feed rate of 24–32 ml/min.

Water absorption index. The result of our calculations is the established influence of the model parameters on the water absorption index. An increase in the temperature at the inlet by 1 measurement unit leads to an increase in the water absorption index by an average of 2.967 units. An increase in the feed rate by 1 measurement unit leads to a decrease in the absorption index by

an average of 0.579 units. The statistical significance of the equation was verified using the coefficient of determination and the Fisher criterion. It was found that in the examined event, 38.36 % of the total variability Y is explained by a change in the factors. Note that it is necessary to exclude the influence of the feed rate factor from the formula (Fig. 4).
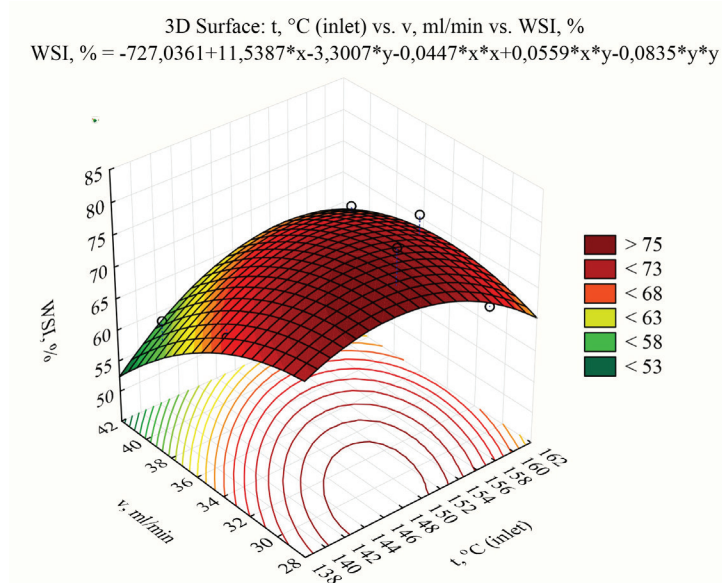
3D Surface: t, °C (inlet) vs. v, ml/min vs. WSI, %
WSI, % = -727,0361+11,5387*x-3,3007*y-0,0447*x*x+0,0559*x*y-0,0835*y*y

Fig. 3. Response surface of the dependence of the water solubility index on the temperature at the inlet and the feed rate

3D Surface: t, °C (inlet) vs. v, ml/min vs. WAI, %
WAI, % = 1025,7064-13,1092*x+4,4478*y+0,0829*x*x-0,3523*x*y+0,7337*y*y
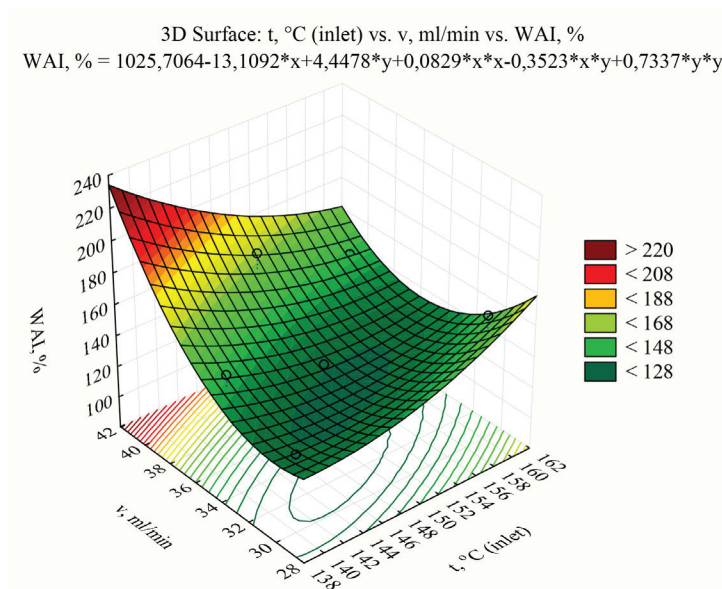

Fig. 4. Response surface of the dependence of the water absorption index on the inlet temperature and feed rate

Moisture content. An increase in the temperature at the inlet by 1 °C leads to a decrease in the moisture content by an average of 0.0504 %. Increasing the feed rate by 1 ml/min leads to an increase in the moisture content in the finished product by an average of 0.069 %. Based on the maximum coefficient, $\beta_2=0.53$, we conclude that the greatest influence on the moisture content in dry milk is exerted by the

feed rate of camel milk. The statistical significance of the equation was verified using the coefficient of determination and the Fisher criterion. It was found that in the examined event, 87.81 % of the total variability of the quantitative moisture content is explained by a change in the selected factors. It was also established that the parameters of the model are statistically significant (Fig. 5).

Hygroscopicity. An increase in the inlet temperature by 1 °C leads to an increase in the hygroscopicity by an average of 0.351 %. Increasing the feed rate by 1 ml/min leads to a decrease in the hygroscopicity by an average of 0.172 %. Based on the maximum coefficient, $\beta_1=0.503$, we conclude that the factor x_1 has the greatest influence on the result Y. The statistical significance of the equation was verified using the coefficient of determination and the Fisher criterion. In the examined model, 49.45 % of the total variability of hygroscopicity is explained by a change in the selected factors (Fig. 6).

Bulk density. An increase in the temperature at the inlet by 1 °C leads to a decrease in the bulk density by an average of 0.00687 g/cm³. An increase in the feed rate by 1 ml/min leads to an increase in the bulk density by an average of 0.00536 g/cm³. Based on the maximum coefficient, $\beta_2=0.754$, we conclude that the greatest influence on the result related to bulk density is exerted by the feed rate factor of the raw materials. The statistical significance of the equation was verified using the coefficient of determination and the Fisher criterion. It was found that in the examined event 80.17 % of the total variability of the bulk density is explained by a change in the factors $x_{1,2}$. The formula is statistically significant and reliable (Fig. 7, *a*).

Density after shaking. With an increase in the inlet temperature by 1 °C, the density after shaking decreases by an average of 0.00723 g/cm³. An increase in the feed rate of the raw materials by 1 ml/min leads to an increase in the density after shaking by an average of 0.00599 g/cm³. Based on the maximum coefficient, $\beta_2=0.76$, we conclude that the factor x_2 has the greatest influence on the result Y. The statistical significance of the equation was verified using the coefficient of determination and the Fisher criterion. It was found that in the examined event 78.72 % of the total variability y is explained by a change in the selected factors (Fig. 7, *b*).

Water activity. An increase in the feed rate by 1 measurement unit leads to an increase in the water activity by an average of 0.0057 units. An increase in the temperature at the inlet by 1 measurement unit leads to a decrease in the water activity by an average of 0.00702 units. Based on the maximum coefficient, $\beta_1=0.363$, we conclude that the greatest influence on the result related to water activity is exerted by the feed rate factor of the raw materials. The statistical significance of the equation was verified using the coefficient of determination and the Fisher criterion. It was found that in the examined event 92.95 % of the total variability of the water activity is explained by a change in the selected factors. It was also established that the parameters of the model are statistically significant (Fig. 8).

Stickiness. With an increase in the feed rate of the raw materials by 1 measurement unit, the stickiness of milk powder increases by an average of 3.338 units. An increase in the temperature at the inlet by 1 measurement unit leads to a decrease in the stickiness by an average of 1.321 units. The statistical significance of the equation was verified using the coefficient of determination and the Fisher criterion. It was found that in the examined event 98.26 % of the total variability of stickiness is explained by a change in the selected factors (Fig. 9).
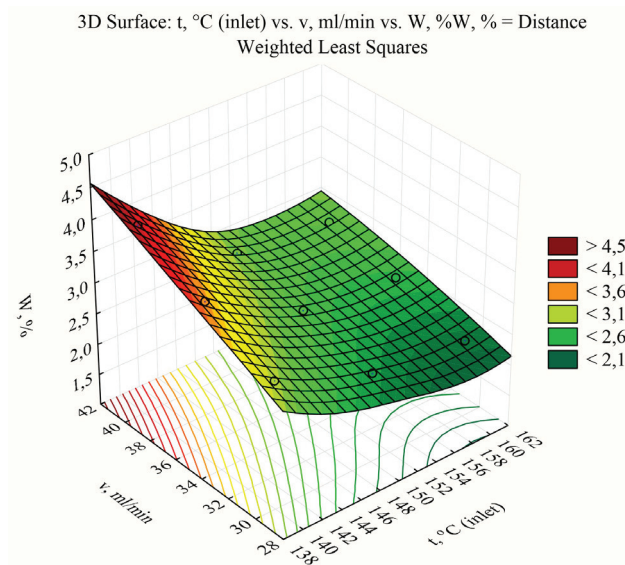

Fig. 5. Response surface of the dependence of moisture content on the inlet temperature and feed rate
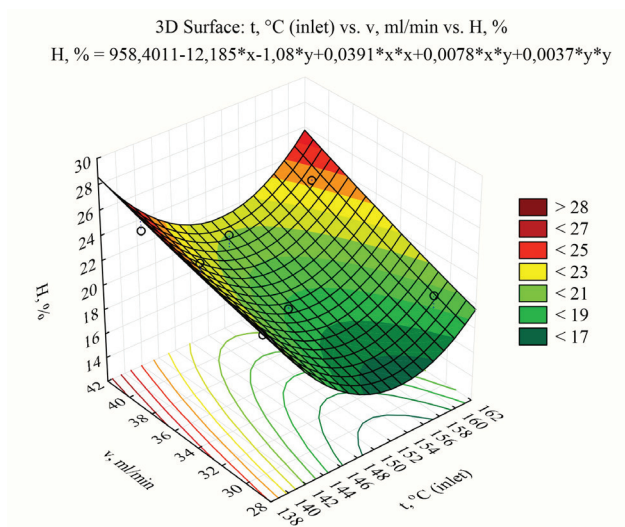

Fig. 6. Response surface of hygroscopicity dependence on the inlet temperature and feed speed

Particle sizes: $d(0.1)$, $d(0.5)$, and $d(0.9)$. With an increase in the temperature at the inlet by 1°C, there is a decrease in the diameter of the particles by an average of 1.568 measurement units. An increase in the feed rate of the raw materials by 1 measurement unit leads to an increase in the diameter of milk powder particles by an

average of 3.392 units. Based on the maximum coefficient, $\beta_2=0.574$, we conclude that the greatest influence on the result related to the particle diameter is exerted by the factor of the feed rate of the raw materials (Fig. 10, *a−c*).
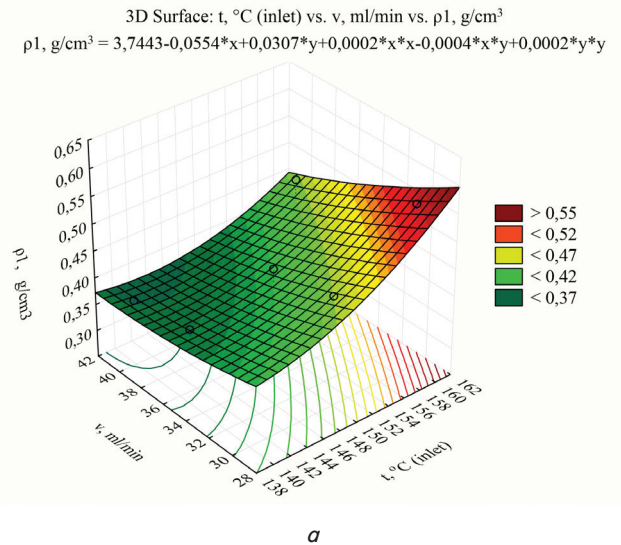
a
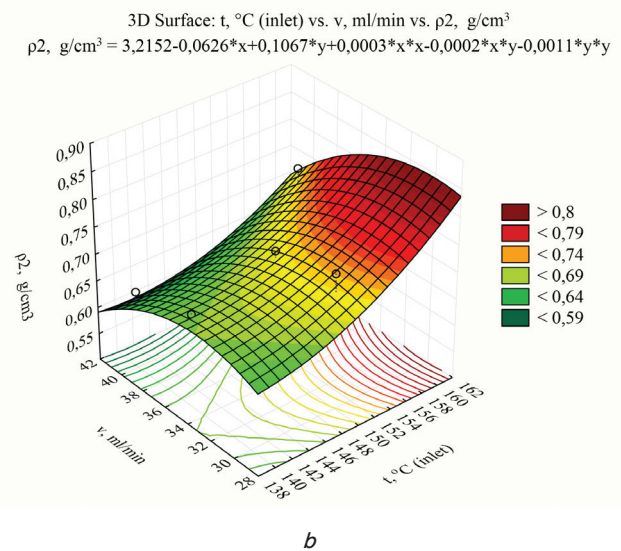
b

Fig. 7. Response surface of the dependence of density on the inlet temperature and feed rate:
a — bulk density; *b* — density after shaking

Mathematical modeling of the spray drying process of camel milk has shown that the best physical properties of the powder are achieved at the inlet air temperature of 150 °C and the raw material feed rate of 30 ml/min.

6. Discussion of results of determining the physical parameters of whole camel milk powder

The physical properties of milk powder are the main indicators that determine the consumer characteristics of the product. These include a water solubility index, a water absorption index, hygroscopicity, bulk density, density after shaking, water activity, stickiness, and particle sizes. While

a potential consumer determines the quality of milk powder by its solubility, then this property directly depends on the absorption index, the size and shape of the particles. In addition, its shelf life is affected by its hygroscopicity, bulk density, water activity, and stickiness. The density after shaking the product determines its transportability.
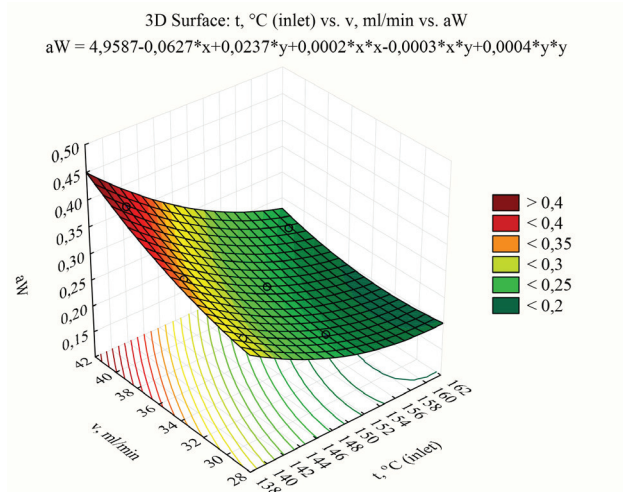
A special feature of the proposed drying method is

3D Surface: t, °C (inlet) vs. v, ml/min vs. aW
aW = 4,9587-0,0627*x+0,0237*y+0,0002*x*x-0,0003*x*y+0,0004*y*y

Fig. 8. Response surface of water activity dependence on the inlet temperature and feed rate

3D Surface: t, °C (inlet) vs. v, ml/min vs. stickiness, g
stickiness, g = 714,2519-8,4469*x+0,7465*y+0,0185*x*x+0,0447*x*y-0,0589*y*y
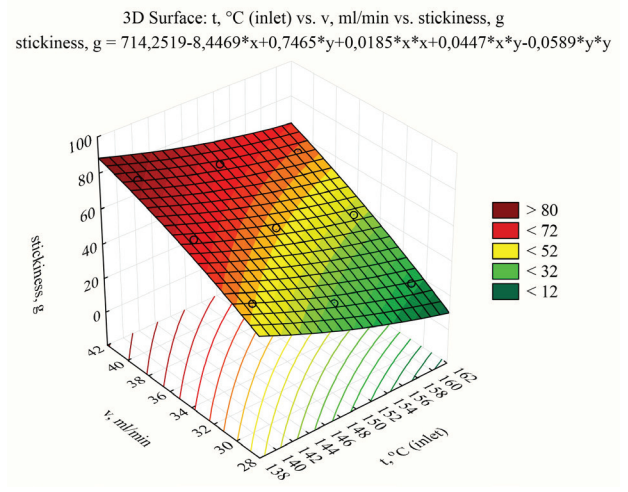
Fig. 9. Response surface of the dependence of stickiness on the inlet temperature and feed rate

that when it is used, improved physical properties of the final product are achieved, better than those with other methods. The water solubility index of dry whole camel milk produced by spray drying was 81.25±0.11 %, which is a good indicator of the solubility of powdered products (Table 1). It was found that solubility depends on the drying method used and the shapes and sizes of the powder particles obtained. Therefore, the spray drying particles, small and grouped into agglomerates, showed good solubility. High indicators of the solubility index in water determine the consumer qualities of milk. Thus, for instant skimmed cow's milk powder, it is at least 95 %, and for whole cow's milk powder – at least 75 % [19].
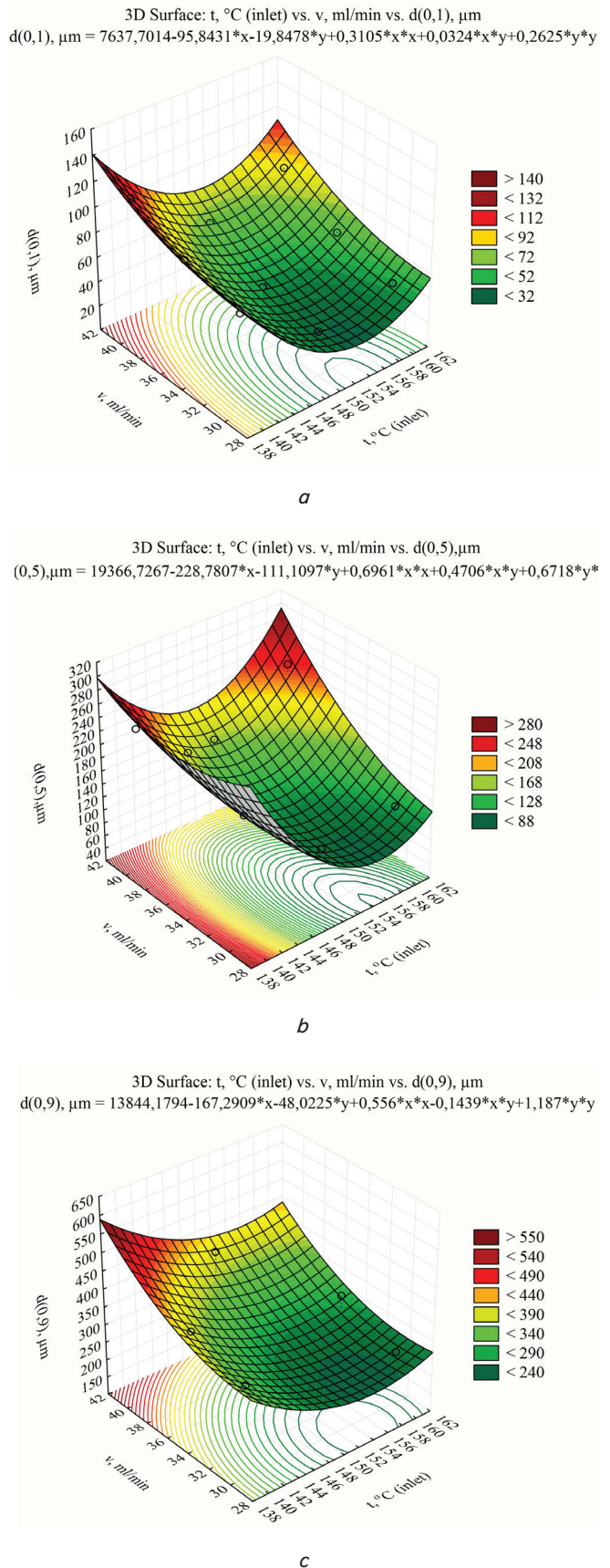
3D Surface: t, °C (inlet) vs. v, ml/min vs. d(0,1), μm
d(0,1), μm = 7637,7014-95,8431*x-19,8478*y+0,3105*x*x+0,0324*x*y+0,2625*y*y

a

3D Surface: t, °C (inlet) vs. v, ml/min vs. d(0,5),μm
(0,5),μm = 19366,7267-228,7807*x-111,1097*y+0,6961*x*x+0,4706*x*y+0,6718*y*

b

3D Surface: t, °C (inlet) vs. v, ml/min vs. d(0,9), μm
d(0,9), μm = 13844,1794-167,2909*x-48,0225*y+0,556*x*x-0,1439*x*y+1,187*y*y

c

Fig. 10. Response surfaces of the particle size dependence on the inlet temperature and feed rate:
a − *d*(0.1); *b* − *d*(0.5); *c* − *d*(0.9)

The absorption capacity of milk powder determines how much water the undissolved sediment can bind. The higher the absorption index, the lower the solubility of the dry powder. For a spray drying sample, this figure was 123.41±0.34 % and is the average water absorption indicator (Fig. 4).

According to standards set in [20], the moisture content in dry milk should not exceed 5 %. The study results showed that this indicator was within the permissibility range – from 2.25±0.11 % to 4.05±0.08 % (Table 1). The low moisture content in dry milk prevents the development of microorganisms and increases its shelf life.

Hygroscopicity determines the storage capacity of the finished product; high hygroscopicity leads to a decrease in the shelf life of the product. Our study has shown that by optimizing the parameters of spray drying, it is possible to achieve a good hygroscopicity index (16.29±0.31 %) (Fig. 6). It was found that hygroscopicity does not depend on the type of raw milk and is directly proportional to the water absorption index. It is also known that products with an indicator of more than 25 % refer to products that have high hygroscopicity [21]. This indicates that the samples do not exceed the norm for hygroscopicity.

According to data in Table 1, at an inlet air temperature of 150 °C and a raw material feed rate of 30 ml/min, the bulk density of the spray drying samples was 0.455±0.05 g/cm^3, and the density after shaking was 0.751±0.07 g/cm^3. The value of bulk density depends on the size of the milk powder particles and the drying technique. The high bulk density of the final product reduces its storage and transportation costs. In addition, depending on the packaging of the finished product, the density after shaking plays an important role in the packaging, storage, and transportation of powdered products. It was found that this indicator depends more on the shaking force used than on the value of the bulk density.

Water activity is one of the main indicators of milk powder, which determines the shelf life and affects its microbiological indicators. The lower the value of water activity, the higher the storability of the product. For the whole camel milk powder samples, this indicator ranged from 0.193±0.04 to 0.401±0.05 (Fig. 8). The results reported by other authors had shown that the activity of water in the samples of powdered milk obtained by spray drying ranged from 0.17 to 0.286, which is also consistent with our data [22].

Stickiness is also an important characteristic of milk powder, determining its dispersibility and solubility. It was found that a decrease in the air temperature at the inlet (140 °C) of the spray tower leads to an increase in the stickiness value (80.42±0.57 g), and an increase in temperature (160 °C) – to a decrease in the stickiness value (22.61±0.55 g) (Fig. 9). Some authors also described that the partial replacement of lactose with maltodextrin leads to a decrease in the stickiness of milk powder, and when replaced with sucrose, on the contrary, it increases. Hydrolysis of whey proteins, which could occur during drying or storage, also led to an increase in the stickiness of milk powder [23].

Sample particle sizes were determined at diameters $d(0.1)$, $d(0.5)$, and $d(0.9)$ in cumulative size distribution. At an inlet air temperature of 150 °C and a feed rate of 30 ml/min, the particle sizes of milk powder were 36.22±0.33 μm, 108.89±0.56 μm, and 229.19±0.74 μm, respectively (Table 1). Such particle size values promote their agglomeration, which improves the dispersibility and solubility of milk powder. Many of the physical properties described above also depend on and stem from particle sizes.

Spray drying towers have large dimensions, which is typical for use in medium and large milk processing enterprises. Therefore, the use of a given drying method and developed technology may be limited by the production capacity of an enterprise.

The disadvantages of this study include a possible decrease in the amount of water-soluble vitamins during the drying process. This is due to the use of relatively high temperatures during the spray drying of camel milk. To determine the possible change in these indicators, in the future it is necessary to study the vitamin composition of camel milk obtained by spraying and freeze-drying methods, where very low temperatures are used.

Further advancement of the current study might involve the application of the drying method for fermented dairy products based on camel milk. Probable difficulties that may arise in this case are associated with the increased acidity of fermented milk products. When fermented foods are exposed to high temperatures, there is a possibility of partial changes in proteins, which could lead to a deterioration in their physical and organoleptic parameters. To address these issues, it is necessary to continue research into optimizing the technological parameters of drying for various dairy products.

7. Conclusions

1. Whole milk powder was manufactured from fresh camel milk using spray drying. We have determined the optimal technological parameters of drying to obtain the resulting product with good physical properties. To this end, the physical properties under different modes of milk drying were comparatively studied.

2. Physical properties such as water solubility index, water absorption index, moisture content, hygroscopicity, water activity, bulk density, density after shaking, stickiness, and particle sizes have been determined. The air temperature at the inlet from 140 °C to 160 °C and the feed rate of raw materials from 30 ml/min to 40 ml/min on the spray drying unit were applied. We have established dependences of the physical parameters on the specified temperature regimes and feed rate.

3. Our calculations have shown that to achieve the improved physical performance of milk powder, it is necessary to use the air temperature at the inlet of 150 °C and the feed rate of raw materials of 30 ml/min. With a decrease in the air temperature at the inlet from 160 °C to 150 °C, an increase in solubility to 23.9 % was observed. At the same time, an increase in the inlet air temperature from 140 °C to 150 °C was accompanied by a decrease in the quantitative moisture content by 20 %. In addition, under the selected technological parameters, the lowest hygroscopicity of whole camel milk powder was achieved (16.29±0.31 %). The data obtained could help in the development and optimization of the production technology of whole camel milk powder with improved physical properties and long shelf life.

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