Comprehensive studies into the influence of various types of preliminary preparation of blueberry berries for drying have established the amount of wax coating, color, and the total duration of dehydration of raw materials. A comparison of 2 types of preliminary preparation was made: hygrothermal treatment and infrared radiation treatment directly during drying. It was established that after treatment with infrared radiation, 53 times more wax plaque came off the berries than after hygrothermal treatment. Microscopic studies of sections of the parenchymal part of berries recorded the state of the cell membranes and the color of the raw materials without prior processing, with pretreatment, and after drying. It was found that berries dried without pretreatment (mode parameters of heat carrier: t=70 °C, v=2 m/s, d=10 g/kg dry air. Win=85 %, $W_з^c$ = 9,3 %) have partially destroyed cell membranes but the color of the dried material is preserved to the maximum. It was observed that the berries after hygrothermal treatment have partially destroyed parts of the cell membrane, which makes it possible to more intensively release moisture from the material after drying, the maximum color of the product is also preserved. In berries, after treatment with infrared radiation of 100 W for 10 minutes, the cells remain convex with partial destruction of the shell of some cells but, after pretreatment, the intensity of color decreases. Studies into the kinetics of drying blueberry berries have confirmed that the use of infrared radiation with a capacity of 100 W for 10 minutes with simultaneous drying under the regime parameters of the heat carrier t=60 °C, v=3 m/s, d=10 g/kg dry air. makes it possible to reduce wax coating on blueberry berries and to intensify thermal moisture exchange during drying of berries better than using hygrothermal treatment

Keywords: convective drying, hygrothermal treatment, infrared radiation, moisture content, mode parameters

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DETERMINING THE INFLUENCE OF PRE-PREPARATION OF BLUEBERRIES (VACCINIUM CORYMBOSUM L.) ON THE TOTAL DURATION OF DRYING

Zhanna Petrova
Corresponding author
Doctor of Technical Sciences, Chief Researcher, Senior Researcher*
E-mail: bergelzhanna@ukr.net

Kateryna Slobodianiuk
PhD, Senior Researcher*

Oleksii Grakov
Postgraduate Student**

*Department of Heat and Mass Transfer in Heat Technologies**
**Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine
Mariyi Kapnist (Zhelyabova) str., 2 a, Kyiv, Ukraine, 03057

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1. Introduction

The cultivation and export potential of blueberry berries (*Vaccinium corymbosum L.*) grown in Ukraine improve every year. Blueberries have gained popularity among consumers because of the results of studies that link their consumption with improved human health [1]. Blueberries have a high content of antioxidant compounds (flavonoids and anthocyanins), vitamins A, B, C, and E, they are well known for their antitumor, anti-inflammatory, and antidiabetic properties [1].

Sugar is the main component of blueberries; the content of dry soluble substances is 65 %. The chemical composition of blueberries includes almost the same amount of glucose and fructose, it does not contain sucrose [2].

Blueberries *Vaccinium corymbosum L.* contain approximately 120 mg of wax/cm^2, which is slightly less than 170 μg/cm^2 in related *Vaccinium elliotti Chapm.* [3, 4]. Blueberries are classified as "waxy" according to Ashton Holloway's Long and Jeffrey wax classification [3].

In fresh berries, all these aforementioned heterogeneous parts (heterogeneous system) are in equilibrium and have approximately the same mass transfer potential. The system, created naturally, is stable at a certain temperature and moisture content of the environment [5].

Berries are grown industrially, are not fully consumed, and the remains need to be processed. One type of recycling is known to be drying.

During the drying process, the balance is disturbed. In this case, the mechanism of moisture transfer will depend on the properties of each element of the system separately. The general direction of moisture movement during the drying process from the center of the berry through a layer of pulp and peel into the environment. So, the movement of moisture and its subsequent release from the berry depends both on the parameters of the environment (on the parameters of the drying agent) and on the properties of the pulp and peel. The transition of moisture from one medium to another depends on the gradient of the transfer potential and occurs from an environment with greater potential to an environment with less potential [6].

During drying, equilibrium conditions are disturbed, the temperature and moisture content of the environment change, as well as the gradient of moisture content at the border of the pulp – the peel. This leads to the transfer of moisture from the inside of the berry to the surface and its evaporation into the environment [7].

From a physiological point of view, the peel with a waxy coating is a protective coating that protects the berry from drying out in natural conditions. But this is also a negative factor for the implementation of the drying process [5]. Therefore, blueberry need proper technological preliminary preparation before the implementation of the main drying process.

It is worth noting that the main feature of blueberry is a high water content, 81–87 % on average [8]. Water is a direct participant in biochemical reactions in living cells [9]. But the composition includes not pure water but cell sap – water with biologically active substances dissolved in it, such as carbohydrates, nitrogenous substances, vitamins, mineral salts, and aromatic substances. Water of cell sap makes up the bulk of the total moisture content of fruits and berries. It is loosely connected to plant tissues and evaporates easily during drying. A small part of the water (10...15 % of the total) is more firmly held by plant colloids and removed with higher energy costs [9].

So, as an object of drying, blueberry have the following features:

– dense wax coating on the peel (120 mg wax/cm^2) [3];

– high water content, about 81–87 % [8];

– the peel is a membrane with poor moisture and vapor resistance, which requires, in order to intensify drying, to develop methods of preliminary preparation of berries, which are aimed at changing these properties [5];

– the presence in the chemical composition of a high content of sugars, as a result, with the removal of moisture during drying, the concentration of the latter in the cell juice increases and slows down further dehydration of blueberry, which can also lead to an increase in energy consumption.

The above forms the scientific topic of research to determine the effect of preliminary preparation of blueberry (*Vaccinium corymbosum L.*) on the total drying time. The results of such studies are of scientific importance as the development of methods for preliminary preparation of blueberries for drying, as well as the choice of rational methods for dehydration of berries. The devised preliminary preparation of raw materials and optimized drying modes could in combination affect the reduction of energy costs. The latter is important for the practical implementation of scientific research on an industrial scale.

2. Literature review and problem statement

In [10], an analysis of existing methods of pretreatment of the peel of berries and fruits was carried out and physical and chemical methods were reported, such as mechanical cutting of berries with a knife blade, chemical additives, or perforation with needles. It has also been reported that due to the presence of unwanted compounds (NaOH, HCl, ethyloleate), waste generation and poor quality of the resulting product, chemical treatment is not a real alternative to weakening the berry peel. Existing studies of osmotic dehydration of cranberries have shown that chemical pretreatment of the peel has led to the lowest value of taste acceptability [11]. The study of pretreatment with liquid nitrogen of blueberry showed a reduction in the duration of drying by 45–65 % but the total phenols are thus significantly lost [12]. The results of research make it possible to exclude the possibility of using the above-listed methods of pretreatment of blueberries before drying since the latter lead to undesirable losses in the biological value of the berries.

The authors of study [10] found that blanching with a steam of berry raw materials has found wide application. Short-term treatment with hot steam or water destroys the honeycomb structure of the wax layer of the berry, which contributes to an increase in the drying rate, which in turn retains anthocyanins. Experiments have shown the advantage of the method of blanching multilayer laying of material relative to a layer of material in 1 row. Blueberry polyphenol oxidase becomes inactive in 2 minutes, more polyphenols are retained [10]. The reported results concerned the juice from the berries. It can be assumed that experiments on whole berries were not included in the research tasks or the conditions were forcedly simplified in advance. Consequently, the issue of increasing the internal pressure of the berry during prolonged external temperature exposure remains unresolved. Indeed, in practice, prolonged exposure to a heated heat carrier (water/steam) for more than 1.5 minutes leads to ruptures of the peel of berries and subsequent leakage of juice. Thus, with the juice, the nutrients of blueberries can be lost.

In [13], the authors investigated the effect of treatment with alkaline solutions, mainly ethyloleate (manufactured by Macklin Biochemical Corporation (Shanghai, China), NaOH and Na_2CO_3 (manufactured by the National Pharmaceutical Corporation (Beijing, China)) on the convective drying of blueberry. The indicated preliminary preparation led to cracking and severe destruction of the wax layer of berries, which significantly accelerated moisture removal during the drying of blueberries. Upon processing, blueberries were dried in one layer with a sample weight of 200 g in a chamber dryer (Shanghai Keheng Corporation, China) at a heat carrier (air) speed of 1.2 m/s. Drying tray had an area of 0.3×0.4 m. The final moisture content was 0.2±0.02 g/g of dry weight. Each treatment was carried out in three repetitions. The authors of study [13] did not report for what reasons the heat carrier velocity of 1.2 m/s was chosen. The low speed of the heat carrier is due to the structural features of the equipment. The above pretreatment can significantly enhance the process of dehydration of blueberries by damaging the wax layer but the taste, aroma, and texture of dehydrated blueberries have changed. It can be assumed that the remnants of chemical additives lead to food safety risks. All this gives reason to argue that it is advisable to conduct research on the development and further determination of the effect of hygrothermal treatment on blueberry and the kinetics of convective drying of berries.

Compared to pre-treatment – steaming, mechanical pretreatment is the best way to preserve the characteristics of berries because it has almost no effect on the quality of the fruit as a whole. Cutting into two or four equal parts of berries is the simplest mechanical pretreatment before drying but this method is not suitable for soft berries. For soft berries before drying, a method of forming many small holes (pores) on the epidermis is proposed, which speeds up the drying of berries [14]. This method, based on the use of a carbon dioxide laser, was tested by the authors of [14] for blueberries. Perforation with a carbon dioxide laser (CO_2 laser) with a power of 100 W made it possible to create micro-holes on the skin of thawed berries in the form of a square grid with a density of 2.0×2.0 mm, which improved moisture removal. The latter is complicated by the presence of a dense wax coating on the surface of the peel of berry raw materials. After perforation with a CO_2 laser, blueberries were re-frozen (at –35 °C), then dried by sublimation with a pressure in the chamber of 13 Pa, the temperature of the condenser –85 °C, the shelf temperature of 20 °C, and the air temperature of 20 °C to the final moisture content of 13–15 % [14]. The method under consideration has not become common for industrial use. Re-freezing of samples leads to an increase in energy costs, which is not desirable for the already expensive-cost method. The issue is still unresolved.

Paper [15] reports a study into the effect of pulsed vacuum drying with heating in the far infrared range [16] on the drying characteristics of fresh blueberry and the quality indicators of the material. The researchers reported that the conditions for pulsed vacuum drying with heating in the far infrared range significantly affects the drying time and quality parameters of dried products, in particular color and cohesion. Compared to drying with hot air at the same drying temperature, pulsed vacuum drying with heating in the far infrared range reduced drying time by 32.14 %. Nevertheless, the results are obtained in the laboratory. It can be assumed that the cost of technological equipment and the complexity of the technology can lead to a high cost of the resulting product. Therefore, it is advisable to find cost-effective pretreatment methods that are available for industrial implementation.

In [17], the study was carried out on fresh blueberry, which were pretreated with pulsed electric fields (IEP) at 2 kV/cm, and then dried at 45, 60, and 75 °C using ordinary hot air or vacuum drying. The characteristics of drying and changes in moisture content, anthocyanins, general phenolic compounds, vitamin C, antioxidant activity in blueberries during drying have been investigated. The researchers reported the effect of IEP pretreatment on drying efficiency and nutritional quality of blueberries depending on drying methods and temperatures. Pretreatment with IEP before vacuum drying significantly reduced the drying time of blueberry samples from 6 to 4 hours, 10–7 hours, and 70–40 hours at 75, 60, and 45 °C, respectively. The pretreatment with IEP did not significantly affect the preservation of nutritional values before drying, and also had the least impact on the nutritional quality of the dried samples during vacuum drying at 75 °C compared to the control. But there remained questions related to the scaling of the results obtained in industrial conditions. The reason for this may be the high cost of technological equipment and the cost of the resulting product. Therefore, it is advisable to find ways to reduce the cost of pretreatment methods and their feasibility for further industrial implementation.

The authors of paper [18] reported the effect of pulsed electric field treatment at 2 kV/cm before osmotic dehydration at 40 °C in a 70-% sugar cane syrup of fresh blueberry. Compared to pre-processed blueberry samples, pretreatment reduced the osmotic dehydration time of blueberry samples from 120 to 48 hours. During osmotic dehydration, a decrease in the content of anthocyanins, predominant phenolic acids and flavonols, the total content of phenols and antioxidant activity in blueberries was observed. The results show that pretreatment with pulsed electric fields significantly reduced the dehydration time. The authors noted that processing improved the microbiological quality of blueberries without affecting its nutritional quality. However, a decrease in the content of anthocyanins, predominant phenolic acids and flavonols, the total content of phenols and antioxidant activity in blueberries during osmotic dehydration, as reported in [18], indicate an unsuccessful combination of treatment with pulsed electric fields with osmotic dehydration.

In the scientific literature, most research considers comparing the drying with infrared radiation with different heat flux with convective drying at different regime parameters. Also, foreign scientists have in-depth analyzed [1] studies that focus on combining drying with infrared radiation (IR radiation) with simultaneous sublimation of blueberries with different time intervals of activation. But there are no data on exactly how short-term infrared radiation treatment at the beginning of the convective drying process affects the total duration of dehydration to a given final average moisture content of the material.

In addition to preliminary preparation, it is necessary to rationally approach the choice of the main method of drying. Vacuum, sublimation, and their subsequent combination: infrared-sublimation, vacuum-sublimation, as methods of processing blueberries are widely used. But these methods are long-term, energy-intensive, and expensive [7]. Their specific energy consumption is 157; 495,1; 233,6–297,9; 331.5–425.2 MJ/kg of water, respectively. So, the review of literary data showed that the processing of blueberry for dried products is practically absent under industrial conditions. All known methods of preliminary preparation, the main stages of dehydration [7] are developed and implemented in the laboratory.

Based on the generalized review of the literary data, further research at the first stage requires solving the problem of improving moisture removal from blueberries by developing pretreatment of berries before drying. In the second stage, it is equally important to determine the impact of the preliminary preparation of blueberry (*Vaccinium corymbosum L.*) on the total duration of drying. Solving these tasks could affect the overall energy costs of the process as a whole.

3. The aim and objectives of the study

The purpose of our research is to determine the features of the influence of the type of preliminary preparation of blueberry on the total duration of dehydration. The developed preliminary preparation of raw materials and optimized drying modes can, in combination, affect the reduction of energy costs. The results are aimed at the practical implementation of scientific research on an industrial scale.

To accomplish the aim, the following tasks have been set:

– to determine the effect of preliminary preparation of blueberries on the amount of wax on blueberry after pretreatment;

– to investigate the effect of preliminary preparation of blueberries on the cell membrane of the parenchymal part of the berries;

– to determine the kinetic drying curves under different technological modes.

4. The study materials and methods

The object of this study is seasonal blueberry (*Vaccinium corymbosum L.*). The main drying process took place after picking berries for 3 days.

Dense wax coating on the peel is a prerequisite for the development of preliminary preparation of berries before drying. The latter will improve the moisture and vapor permeability of the peel, which can further affect the heat and mass transfer during dehydration of the berries.

During the research, 2 methods of preliminary preparation were applied, which are available for implementation on an industrial scale, namely:

1) hygrothermal processing, which involves blanching blueberry in a steam water bath;

2) treatment with IR radiation of 100 W directly during drying.

The most important technological operation that precedes the drying process is hygrothermal treatment. The quality and nutritional value of the finished product depends on the correctness of the latter [19, 20]. Preliminary preparation, depending on the mode of its implementation, can affect the peel of blueberry. On the one hand, under thermal influence, partial removal of substances of wax plaque, changes in its structure and properties are possible. On the other hand, under the action of heat, mechanical deformation is possible, which leads to microcracks and partial peeling from pulp, contributing to the formation of ways to move moisture. Hydrolysis of substances that cement peel cells is also possible. Thus, hygrothermal treatment can both speed up drying and slow it down with a further increase in energy costs.

Hygrothermal treatment involves inspection, washing blueberry, blanching in a steam bath.

It has been suggested that heating with infrared radiation can affect the wax coating of blueberry no worse than hygrothermal treatment. Infrared radiation (IR radiation) is electromagnetic radiation covering the wavelength range from 0.75 to 1000 microns. The mechanism for absorbing the energy of infrared waves is to change the vibrational state of the molecules. In general, solid materials absorb infrared radiation only in a thin surface layer. In porous wet materials, radiation penetrates to a certain depth, and their conductivity depends on the moisture content. The absorption of IR energy by water prevails at all wavelengths, which allows the use of a wide range of infrared emitters [21, 22].

For the purpose of pretreatment of blueberry, an IR-emitting lamp with a power of 100 W with a heat flux of 3800 W/m^2 was used. The sample was aged for up to 10 minutes under the influence of infrared radiation during direct drying in the chamber of the experimental bench. Then the lamp was turned off and further convective drying took place under the operating parameters of the heat carrier t=60 °C, v=3 m/s, d=10 g/kg dry air to residual moisture content $W_r^a = 12.65$ %.

In order to determine the effectiveness of the influence of preliminary preparation on the amount of wax coating of blueberry peel. The method is based on the ability of wax coating to melt under the influence of an external heat source (heated steam, IR radiation, etc.). The mass of wax to be removed was determined by the difference in the mass of the batch of blueberry before and after processing. Measurements were carried out on high-precision scales VLA-200g-M (USSR). The photofixation method was used for fixation and visualization for further analysis of the dynamics of the process of reducing wax plaque after exposure to an external heat source (heated steam, IR radiation) on berries.

Microstructural studies into the effect of berry pretreatment on the permeability of blueberry shell were performed using the universal motorized light microscope Axio Imager Z1M (Carl ZEISS, Germany), which is equipped with a microphotography camera and software.

To study the kinetics of the drying process of blueberry treated hygrothermally and using infrared radiation, a convective experimental bench was used, developed at the Institute of Technical Thermophysics of the NAS of Ukraine in the Department of Heat and Mass Transfer in Heat Technologies. The research program provides for the identification of the basic laws of drying of plant materials in a wide range of changes in factors with the automatic collection and processing of information on changes in mass, sample temperature in time increments of 15 seconds, and calculations of kinetics. The bench is equipped with a working chamber, heat carrier heating zone, fan, potentiometer, control panel, scales, water vapor generator, regulating autotransformer, psychrometer, and Pito tubes with micromanometer. The design of the bench has a system of insulated air ducts with devices for heating and circulation of heat carrier, drying chambers (including with IR lamps), systems for monitoring and maintaining the temperature of the heat carrier, automatic collection and processing of information about the kinetics of the material drying process [19]. Studies were conducted in 3 repetitions.

5. Results of studies into determining the effect of preliminary preparation of blueberry (*Vaccinium corymbosum L.*) on the total duration of dehydration

5. 1. Determining the effect of pre-preparation of blueberries on the amount of wax on blueberry after pretreatment

The results of measurements of changes in the mass of blueberry before and after pretreatment are given in Table 1.

Fig. 1, 2 shows photos of the appearance of blueberry before and after processing.

Table 1

Measurement results of changes in the mass of blueberry before and after pretreatment

No. of entry	No. container	Mass of the container, m_c, g	Mass of the container with sample, m_{c+s}, g	Weight of a sample of fresh berries, m_s, g	Type of pretreatment			
					Blanching on a steam bath		IR-irradiation	
					Mass of the container with sample, m_{c+s}, g	Weight of a sample of processed berries, m_s, g	Mass of the container with sample, m_{c+s}, g	Weight of a sample of processed berries, m_s, g
1	3	47.2971	53.3091	6.012	53.3076	6.0105	–	–
2	2	50.8302	57.2759	6.4457	–	–	57.1963	6.3661

Visually, you can see that IR-radiation treatment can significantly reduce the amount of visible wax coating of berries, in contrast to hygrothermal treatment.

a *b*

Fig. 1. Photos of the appearance of blueberry before hygrothermal treatment and after: *a* – before hygrothermal treatment; *b* – after hygrothermal treatment

a *b*

Fig. 2. Photos of the appearance of blueberry before infrared radiation treatment and after: *a* – before infrared radiation treatment; *b* – after infrared radiation treatment

Our analysis of the resulting data revealed that after hygrothermal treatment, 0.0015 g or 1.5 mg of wax plaque came off, and after treatment with infrared radiation, 0.0796 g or 79.6 mg of wax plaque came off, which is 53 times more. Therefore, treatment with infrared radiation is more efficient and appropriate for blueberry.

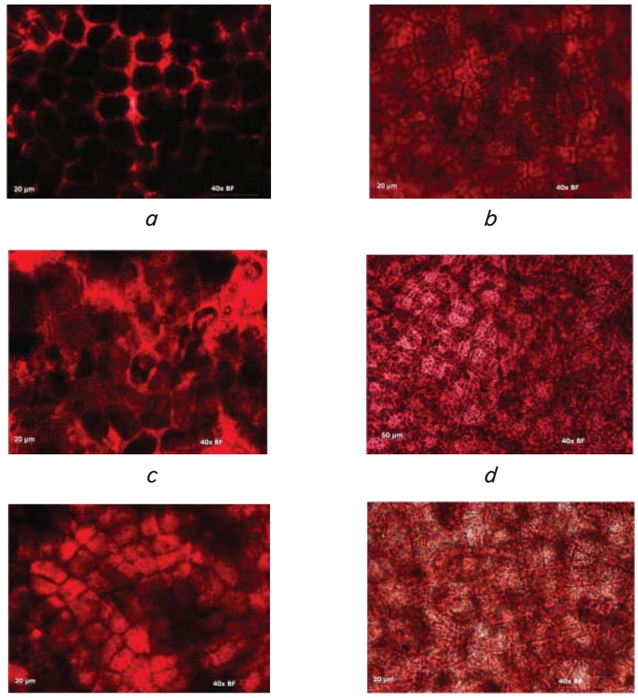
5. 2. Microscopic studies of the effect of preliminary preparation of blueberries on the cell membrane of the parenchymal part of the berries

The research results are shown in Fig. 3.

Fig. 3, *a* shows a photo under a microscope of a cut of the parenchymal part of the blueberry berry before drying. The photograph demonstrates clear convex, not destroyed cells in which the coloring substances are concentrated.

Fig. 3, *b* shows a photo under a microscope of a cut of the parenchymal part of the dried blueberry berry without pretreatment (mode parameters of the heat carrier: t=70 °C, v=3 m/s, d=10 g/kg dry air, initial moisture content of the material W_{in}=85 %, $W_r^a = 9.3$ %). The photo demonstrates that after drying according to the above modes, the cell membranes are partially destroyed but the color of the dried material is preserved as much as possible.

Fig. 3, *c* shows a photograph under a microscope of a cut of the parenchymal part of the blueberry berry after hygrothermal treatment for 1–1.5 minutes. The photo shows that after processing, parts of the cell membrane are partially destroyed, which makes it possible to more intensively release moisture from the material during drying; the maximum color of the product is retained (Fig. 3, *d*).



a *b* *c* *d* *e* *f*

Fig. 3. Image of blueberry berry cells in 40x magnification: *a* – without processing; *b* – dried without pretreatment (mode parameters of heat carrier: t=70 °C, v=3 m/s, d=10 g/kg dry air W_{in}=85 %, $W_r^a = 9.3$ %); *c* – after hygrothermal treatment, 1–1.5 min; *d* – dried hydrothermally treated (mode parameters of heat carrier: t=60 °C, v=3 m/s, d=10 g/kg dry air W_{in} =85 %, $W_r^a = 22.7$ %); *e* – treated with infrared radiation with a power of 100 W for 10 minutes; *f* – dried, treated with infrared radiation with a power of 100 W for 10 minutes with simultaneous convective drying (N=100 W, t=60 °C, v=3 m/s, d=10 g/kg dry air, W_{in}=85 %, $W_r^a = 12.65$ %)

After processing blueberry with IR radiation with a power of 100 W for 10 minutes (Fig. 3, *e*), the cells remain convex with partial destruction of the shell of some cells but after pretreatment, the intensity of the color of the dried berry decreases (Fig. 3, *f*).

5. 3. Determination of kinetic drying curves

Studies into the kinetics of drying blueberry without processing and after hygrothermal treatment were carried out under constant regime parameters of the heat carrier (air) t=70 °C, v=2 m/s, d=10 g/kg dry air. The nature of the dehydration process is represented in the form of drying curves characterizing the change in the average (integral) moisture content of the material W^a over time τ in Fig. 4.

Due to their biochemical properties, blueberry are a complex drying object that requires a lot of time for dehydration. As mentioned above, wax interferes with moisture removal. In this case, a “soft” mode is applied to the drying of the berries, that is, a low temperature of the heat carrier and the speed of movement of the latter at a sufficiently high moisture content of the material [23].

In this case, the decrease in the average moisture content of the berries is slow and the plots in Fig. 4 (curves 1 and 2) take the form of curves with a bulge heading towards the W^a axis.

Fig. 4 demonstrates that the use of hygrothermal treatment can reduce the amount of wax on blueberry and thereby reduce the total duration of the dehydration process by 1.04 times (curve 2) relative to unprocessed berries (curve 1).

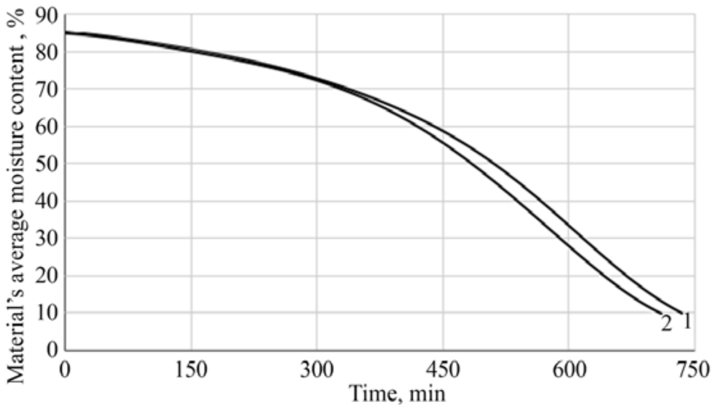


Fig. 4. The kinetics of drying without processing and pre-processed blueberry. Mode parameters of heat carrier: t=70 °C, v=2 m/s, d=10 g/kg dry air. 1 layer. $W_r^a = 9.3$ %; 1 – blueberry berries without processing (total duration of dehydration τ=741 min); 2 – pre-hygrothermally processed berries (total duration of dehydration τ=714 min)

The results of our study into the kinetics of the drying process of blueberry, depending on the type of processing (1 – pre-hygrothermally processed berries; 2 – berries are treated with infrared emitters of 100 W (τ=10 min) at the beginning of drying) in the form of drying curves are shown in Fig. 5.

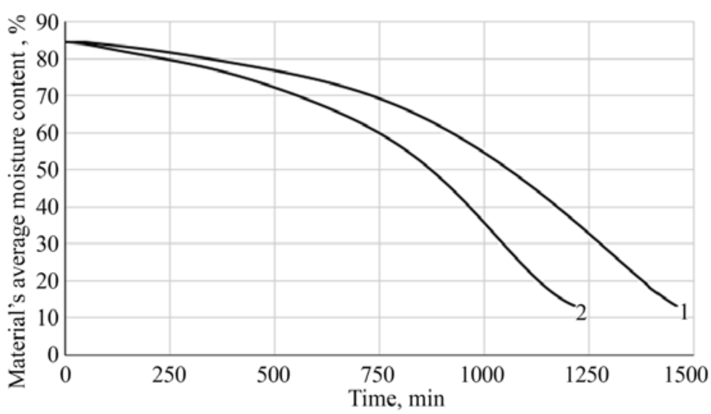


Fig. 5. The kinetics of drying blueberry, depending on the type of processing. Mode parameters of heat carrier: t=60 °C, v=3 m/s, d=10 g/kg dry air. 1 layer, $W_r^a = 12.65$ %; 1 – pre-hygrothermally processed berries (total duration of dehydration τ=1468.15 min); 2 – berries are treated with infrared emitters with a power of 100 W (τ_p=10 min) at the beginning of drying (total duration of dehydration τ=1219.35 min)

The experiment used an infrared source with a thermal power of 100 W, which heated the surface of blueberry berries that did not have pretreatment. Heating with infrared radiation lasted for 10 minutes with simultaneous drying under the regime parameters of the heat carrier (air) t=60 °C, v=3 m/s, d=10 g/kg dry air. IR lamps were located at a height of 0.07 m from the sample, the initial mass of the layer of which was 65 g with a moisture content of 85 %.

As noted above, the use of 100 W infrared radiation reduces the amount of wax on blueberry relative to hygrothermal treatment and thereby reduces the total duration of the dehydration process by 1.2 times (Fig. 5).

6. Discussion of results of investigating the impact of the preliminary preparation of blueberry (*Vaccinium corymbosum L.*) on the total drying time

Our studies to determine the amount of wax coating on blueberry after pretreatment experimentally confirmed the assumption, namely: heating with infrared radiation can affect the wax coating of berries no worse than hygrothermal treatment. The result showed that the use of an IR-emitting lamp with a power of 100 W with a heat flux of 3800 W/m^2 made it possible to remove wax plaque by 53 times more on the skin of berries than hygrothermal treatment. This is also confirmed by visual observations, which can be easily traced from the comparison of photographs of berries after hygrothermal treatment (Fig. 1, *b*) and after treatment with infrared radiation (Fig. 2, *b*).

Microscopic studies made it possible to obtain a scientific understanding and to assess in more detail the effect of preliminary preparation on the cell membrane of the parenchymal part of blueberry. Comparing the obtained images of blueberry berry cells (Fig. 3) demonstrates that the berries, treated hygrothermally or with IR-radiation, equally have partially destroyed parts of the cell membrane. This allows moisture to be more intensively released from the material during drying. Obviously, infrared radiation penetrating into the cells partially destroys the dye, which is further visible in Fig. 3, *e* of the dried material. There are enough coloring substances, and it can be recommended for use.

Investigating the kinetics of drying blueberry, depending on the type of preliminary preparation for drying under different regime parameters of the heat carrier, confirmed previous assumptions. Treatment with IR radiation of 100 W makes it possible to reduce the wax coating on berries and intensify thermal moisture exchange during drying of berries. The results of kinetic curves in Fig. 4, 5 indicate a positive effect of hygrothermal treatment and the thermal effect of 100 W infrared radiation on reducing the total drying time. The latter on an industrial scale can have a positive effect on reducing energy costs.

In this case, treatment with IR radiation of 100 W is an integral part of the drying process and lasts a minimum period of time (τ=10 minutes). And the hygrothermal treatment of berries as well as other well-known methods of preliminary preparation of blueberry is a separate stage of technological preparation before drying, which requires additional energy costs. Thus, the processing of berries with an infrared radiation of 100 W up to 10 minutes during drying in the future will reduce the number of technological operations during the processing of blueberries into dried products. But to confirm this, the experimental data obtained in the laboratory need to be tested under industrial conditions.

The limitation of the study is that the results were obtained under controlled laboratory conditions. Scaling in industrial environments requires additional research. The results for hygrothermally processed blueberry in the range of 1–1.5 minutes may vary slightly since the duration of exposure to steam on the parenchymal part of the berry may be reflected in the moisture-removal mechanism.

The disadvantage of the study is the high duration of dehydration of blueberry as a colloidal capillary-porous material. There is an additional problem of the Loss of coloring substances of berries. The existing problem should be solved only through two methods that can be improved in further research. So, all this together forms the vector of further area of research.

7. Conclusions

1. It was found that hygrothermal treatment by blanching on a steam bath for 1–1.5 minutes makes it possible to reduce wax coating on blueberry and intensify heat and moisture exchange at the beginning of drying. From the analysis of the obtained data, it was found that after treatment with infrared radiation with a power of 100 W (τ=10 min), wax plaque came of 53 times more than after hygrothermal treatment on a steam bath. Berries did not receive mechanical deformations. Consequently, IR radiation treatment is more effective for removing wax coating and is appropriate for berries.

2. Additionally, microscopic studies found that after hygrothermal treatment for 1–1.5 minutes, parts of the cell membrane were partially destroyed, which makes it possible to more intensively release moisture from the material after drying, the maximum color of the product is also preserved. After processing blueberry with IR radiation of 100 W for 10 minutes, the intensity of color decreases, penetrating into the cells partially destroying the dye.

3. The use of hygrothermal treatment reduces the total duration of the dehydration process by 1.04 times relative to unprocessed berries. At the same time, the use of 100 W IR radiation for 10 min with simultaneous convective drying of fresh blueberries reduces the total duration of the dehydration process by 1.2 times relative to hygrothermally processed berries. However, we recommend using 100 W infrared radiation for up to 7 minutes in order to prevent the Loss of coloring substances.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The data cannot be provided for the reasons specified in the data availability statement.

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